REMARKS

Applicants thank the Examiner for the thorough consideration given the present application. Claims 1-3, 5, 6 and 8-11 are currently being prosecuted. The Examiner is respectfully requested to reconsider his rejections in view of the amendments and remarks as set forth below.

Entry of Amendment

It is respectfully requested that the present amendment should be entered in the official file in view of the fact that the amendments to the claims automatically place the application in condition for allowance. Alternatively, if the Examiner does not agree that the application is in condition for allowance, it is respectfully requested that the present amendment should be entered for the purpose of appeal.

Rejections under 35 U.S.C. §§ 102 and 103

Claims 10 and 11 stand rejected under 35 U.S.C. § 102 as anticipated by, or in the alternative under 35 U.S.C. § 103 as being obvious over Arakawa et al. (U.S. Patent 6,297,920). This rejection is respectfully traversed.

The Examiner states that Arakawa et al. teaches a method of compressing lumber using a shaping jig. A vinyl monomer is used to

fill cracks and vacancies in the wood. The Examiner points out that these claims are considered product claims and that any method limitations are considered product by process type limitations.

Claim 10 describes a permanently compressed lumber having a combination of features, that include being formed by compressing and dry heating porous lumber, in which many holes are formed in an edge portion by pine wood nematodes, which remarkably reduce density of the edge portion, in a compressing die including a male die section and female die section, and having flexural rigidity of 130 Mpa or more. Applicants submit that the reference does not teach this combination of features. Likewise, claim 11 teaches a permanently compressed lumber having a combination of features including being formed by compressing and dry heating porous lumber in which many holes are formed in an edge portion by pine wood nematodes, which remarkably reduce density of the edge portion and including a functional additive which is filled in the many holes. Applicants likewise submit that the reference does not teach this combination of features. In particular, Applicants submit that the reference does not teach the porous lumber as described.

This type of lumber has many holes formed in an edge portion by insects called pine wood nematodes. These holes reduce the density of the edge portion. Concerning the term "pine wood nematodes", this is the name of an insect. In the original English

translation, the term utilized was "pine bark and wood borer, etc.". This name change is an attempt to find a suitable English translation for the name of the insect. Applicants are submitting as Exhibit A, a document entitled "*The Pine Wood Nematode and the Japanese Pine Sawyer*" by Yoichi Kishi to support the use of this term.

The cited reference teaches a method of compressing and shaping lumber into a desired shape including the steps of: preheating the lumber, whose moisture content is 10-80 wt% to around 100°C so as to soften the lumber; and compressing and shaping the lumber in a fluid. However, even if the lumber was preheated in this manner and compressed, the compressed shape lumber is not sufficiently fixed. This problem has been described in a document submitted herewith as Exhibit E from the *Journal of Japan Wood Research Society*, Vol. 44, No. 6, pages 410-416 (1998). This documents discloses a method of heat compressing wood. In the method, wood specimens are compressed by preheating the specimens by irradiating with high frequency waves until the inner temperature reaches 100°C and compressing the preheated specimens with high frequency heating. Recoveries in the longitudinal direction of the compressed specimens are shown in Figures 4-7 of the *Journal*. The set recoveries in the end parts of the specimens are greater than the center parts. Accordingly, the end parts of

the specimens are insufficiently compressed so that the shapes are not sufficiently fixed. When a restraining jig for restraining the end parts is used, the end parts are also insufficiently fixed (see Figure 7). Since moisture in the end parts evaporates in the air from the end faces as steam, the end parts cannot be sufficiently compressed and fixed by high frequency heating. On the other hand, in the present invention, the set recovery in the longitudinal direction of the test piece is not changed. Accordingly, the lumber can be sufficiently compressed and a shape can be completely fixed.

Applicants are submitting herewith an experiment report as Exhibit B. This experiment report verifies the problems of utilizing a method such as this. Accordingly, Applicants submit that the present invention is not seen by Arakawa et al.

In particular, Arakawa et al. does not describe lumber in which holes are formed on an edge portion to remarkably reduce the density of the edge portion. Thus, the use of the method of Arakawa et al. would not produce a permanently compressed lumber as presently described. Accordingly, Applicants submit that claims 10 and 11 are allowable.

Claims 5, 6, 8 and 10 stand rejected under 35 U.S.C. § 103 as being obvious over Viitaniemi et al. (U.S. Patent 5,685,353). This rejection is respectfully traversed.

The Examiner states that the reference teaches a method of compressing and shaping of wood between upper and lower compression plates. The ends of the wood are not in contact with the plate and are therefore exposed to air. The Examiner states that compressed wood is also heated while under compression. The Examiner feels that the flexural rigidity of the 130 Mpa would be inherently contained.

Applicants submit that the Viitaniemi et al. reference shows a method of two-stage compressing lumber within a pair of plates which can be heated. A compressing force of the second compression stage is smaller than that of the first compression stage. Lumber which has been first compressed recovers its shape at the beginning of the second compression stage so that the second compression stage must be executed for a long time in order to compress the lumber and make the compressed lumber have the prescribed compressibility. The end face of the lumber clamped between the plates are open. If the lumber which is compressed and whose end faces are open, is heated to 100°C or more, moisture in the end parts of the lumber evaporates in the air from the end face as steam so that the end parts cannot be sufficiently compressed and fixed by the heat treatment.

Claim 5 describes a method of permanently compressing lumber including the steps of compressing a porous lumber in which many

holes are formed in an edge portion by pine wood nematodes and which remarkably reduce density in the edge portion, the porous lumber being accommodated and compressed in a compressing die, and dry heating the compressed lumber, the compressed state being maintained in the compressing die for permanently compressing the lumber. Applicants submit that the reference does not teach this combination of steps. In particular, the reference does not describe the lumber as having holes formed on an edge portion by pine wood nematodes. In fact, the reference does not show or suggest the use of such porous lumber at all.

Applicants are submitting Exhibit C which is a photograph of a section of porous lumber. In this lumber, many holes are formed in the edge portion by pine wood nematodes which remarkably reduce the density of the edge portion. The lumber was soaked in a solution of iron oxide. The edge portion of the porous lumber including many cells was wholly stained black by the iron oxide. The strength of the porous lumber in which many holes are formed is normally very low. On the other hand, in the present invention, the useless porous lumber is heated in the compressed state so that the porous lumber can actually be used as well as ordinary hard lumber. In view of this, Applicants submit that claim 5 is allowable over this reference.

Claim 6, 8 and 9 depend from claim 5 and as such are also considered to be allowable. In addition, these claims recite other features of the invention which make them additionally allowable. Thus, claim 6 recites the flexural rigidity of the lumber while claim 8 describes the non-contact face exposed to the air, and claim 9 describes the functional additive. In view of this, Applicants submit that these claims are additionally allowable.

The Examiner also admits that the Viitaniemi et al. reference does not teach a die having male and female sections. The Examiner feels that this would have been obvious to one skilled in the art in place of flat plates, depending on the desired final shape of the wood. Applicants submit that this feature would not be obvious without the teaching of the need to use die sections having this shape. Accordingly, Applicants submit that the claims are additionally allowable due to this limitation.

Claim 10 describes the permanently compressed lumber having a plurality of features, as noted above. Applicants submit that claim 10 is also allowable over this reference since it also does not describe the combination of features and especially porous lumber in which holes are formed in an edge portion by pine wood nematodes which remarkably reduce the density of the edge portion. In addition, the reference does not recite the flexural rigidity

value. Accordingly, Applicants submit that claim 10 is likewise allowable.

Claims 1-3 and 9-11 stand rejected under 35 U.S.C. § 103 as being obvious over Viitaniemi et al. in view of Arakawa et al. The Examiner feels that one of ordinary skill in the art would be motivated to use lumber with a low water content as the wood in the Viitaniemi et al. The Examiner also feels that one of ordinary skill in the art would be motivated to use functional additive to fill cracks.

Amended claim 1 describes a method to permanently compress lumber, including a combination of steps of compressing an air dried lumber whose moisture content is 12 wt% or less in a compressing die without preheat treatment, the air dried lumber being one-stage-compressed with a compressibility of 50% or more, and dry heating the lumber where the compressed lumber is air tightly accommodated in the compressed state. Applicant submit that these references do not teach this combination of steps. In particular, the references do not show the describe moisture content. They also do not teach a compression without preheat treatment in one-stage-compression.

Applicants have now utilized the term "moisture content expressed in percent". This is an expression which is described in the document "*Mechanics of Wood and Wood Composites*" on page 40-41.

This document is identified as Exhibit D. The moisture content is defined in this article as $M=[(w_a-w_0)/ w_0]x100$, where M is the moisture content expressed in percent, w_a is the weight of the sample prior to drying and w_0 is oven-dried weight of the sample. This parameter is different than the water content described in the references. Since the references do not show lumber having this type of moisture content, Applicants submit that the claims are allowable. Furthermore, claim 1 describes the lumber as being without a preheat treatment. Also, the lumber is described as being "one-stage-compressed". This differs from Viitaniemi et al. where a two-stage compression is utilized. It also differs from Arakawa et al. which uses a preheating step. Further, the claim describes the dry heating as having the compressed lumber air-tightly accommodated in the compressed state in order to formally compress the lumber. Applicants submit that the references do not show these features even if combined.

CONCLUSION

In view of the above, it is believed that the claims clearly distinguish over the patents relied on by the Examiner, either alone or in combination. In view of this, reconsideration of the rejections and allowance of all of the claims are respectfully requested.

Pursuant to 37 C.F.R. §§ 1.17 and 1.136(a), Applicant(s) respectfully petition(s) for a one (1) month extension of time for filing a reply in connection with the present application, and the required fee of $110.00 is attached hereto.

Should there be any outstanding matters that need to be resolved in the present application, the Examiner is respectfully requested to contact Robert F. Gnuse (Reg. No. 27,295) at the telephone number of the undersigned below, to conduct an interview in an effort to expedite prosecution in connection with the present application.

If necessary, the Commissioner is hereby authorized in this, concurrent, and future replies, to charge payment or credit any overpayment to Deposit Account No. 02-2448 for any additional fees required under 37 C.F.R. §§ 1.16 or 1.17; particularly, extension of time fees.

Respectfully submitted,

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0038-0363P

Attachments: Exhibits A, B, C, D and E

EXHIBIT A

Forest Pests in Japan – No. 1

THE PINE WOOD NEMATODE

and

THE JAPANESE PINE SAWYER

By Yoichi Kishi

Ibaraki Prefectural Forest Experiment Station,

Ibaraki, Japan

Thomas Company Limited, Tokyo, Japan

December, 1995

Price: ¥13,390 (in Japanese yen, tax in Japan included)

ISBN4-9900451-0-6 C3061 P13390E

PART II • PWN (THE PINE WOOD NEMATODE), *Bursaphelenchus xylophilus*

II.0. General.

Pine trees inoculated with thousands of PWN wilt easily. I feel a little apprehensive about research progressing without confirmation of whether such a large number of PWN can attack trees under natural conditions. However, the discovery of PWN is the most important concerning Japanese forest pests. Research papers on PWN and JPS for the 20 years since its discovery are very numerous and substantial.

Section 10. PWN discovery

10.1. Studies on pine bark and wood borers in Japan leading to PWN discovery.

After felling and burning of dead pines was conducted intensively throughout Japan following Furniss's recommendations, pine loss decreased remarkably in the 1950s, and studies on pine damage became rare. However, researchers became interested in pine bark and wood borers again in the 1960s when pine loss in western Japan began to increase in the 1960s.

Researchers in Europe and the U. S. A. had two opposite theories on the ability of bark and wood borers to attack conifers; (1) Bark and wood borers could not kill healthy trees, but could kill weakened ones, (2) bark beetles such as *Dendroctonus* spp. could also kill healthy trees. There was constant controversy concerning these theories, which was reviewed by Dr.C.Nishiguchi (*1330*).

In Japan, Dr. T. Kojima, who had studied in Germany and investigated harmless Curculionidae and Cerambycidae there, considered that pine bark and wood borers in Japan were unable to kill healthy trees (*944, 945*), and Dr. M. Inoue, who had investigated bark beetles in wind damaged trees in Hokkaido pref., agreed with this (*550*). On the other hand, Sata(*1645*), Hidaka(*415*), Nakano(*1308*) and Nitto (*1367, 1368*), who had investigated severe damage in mature and young pine forests in western Japan, considered that pine bark and wood borers over a certain population level were able to kill healthy trees.

To solve this controversy, pine damage patterns in Japan were investigated and classified as follows; (1) Constant damage occurring in overmatured forests, (2) damage occurring in wind damaged forests over several years, (3) severe damage occurring in western Japan and in the southern part of the Kanto district, (4) slight damage occurring in the cold district of Tohoku (*1454*). Bark and wood borers in dead pine trees of each damage pattern were investigated intensively. The results showed that; (1) Bark and wood borers in dead pine trees in the severe damage pattern were characterized by *Monochamus alternatus, Shirahoshizo* (*Cryptorrhynchus*) spp. and *Taenioglyptus fulvus*, whose eggs were laid mainly in summer (*469, 583, 707, 709, 727, 774, 824, 984, 1375, 1380, 1382, 1452, 1454, 1624, 1625*), (2) it was clear that pine trees were killed mainly in summer judging from girth growth and leaf elongation (*1444*).

Bark and wood borers closely connected with severe damage laid eggs in summer. Therefore, the ability of *M. alternatus, Shirahoshizo* spp. and *T. fulvus* to kill trees was investigated by forcing oviposition against healthy trees, and which they could not kill (*618, 710, 723, 725, 2036, 2039*). They could also not kill tide–water damaged pines but could kill some trees weakened by root cutting or stem wiring (*710, 723, 725*). From these forced oviposition studies it was refuted that severe damage occurred by their direct attack. Further evidence supporting this came from studies in clear cuttings of mature and young pine forests, where the oleoresin flow on stumps had already been abnormally low before beetle oviposition (*1383, 1385*).

The relation between oleoresin flow and bark beetle attack had been studied from early times and

Table 11. Methods to measure oleoresin flow

Method	Oleoresin flow	Classification	Oleoresin production (g/24hr)
Polosentzev 1947 (*1616*) A knife cut of 5 cm length is made on stem inner bark of each tree. Within 24 hours, oleoresin flow is classified.	nil resin, sapwood dry	1 (dead)	0
	tiny droplets of resin	2 (dying)	not measured
	small aggregates of resin on wound	3 (recovery possible)	0.02~0.1
	abundant resin not overflowing	4 (a little weak)	0.1~1.22
	abundant resin overflowing wound	5 (healthy)	4.5~4.9
Oda 1967 (*1445*) A section of bark and phloem is removed from the trunk of each tree by knife or cork-borer. After several hours, oleoresin flow is classified.	nil resin, sapwood dry	1 (dead)	–
	tiny droplets of resin	2 (abnormally low)	–
	small aggregates of resin on sapwood	3 (abnormally low)	–
	abundant resin	4 (normal)	–
	abundant resin overflowing wound	5 (normal)	–

was reviewed by Dr. C. Nishiguchi (*1330*). Polosentzev's method was simple and useful to measure oleoresin flow and Oda's method (after Polosentzev) was used in Japan (Table 11). Pines of low oleoresin flow as measured by the Oda method often wilted afterward (*1384, 1386, 1387, 1445, 1446*). Since low oleoresin flow was commonly measured before insect attack, these pines were already physiologically abnormal (*617, 618, 886~888, 1962*).

A working group on controlling pine damage was started in 1968, and pine damage was studied for four years by various researchers on insects, tree diseases, fungus diseases, tree physiology, silviculture, soils etc. (*591*). To clarify the abnormal physiology of pines was one of the most important objectives, but significant results were not produced in the interim report (*122, 592, 607, 683, 1447, 1524, 2072, 2323*).

10.2. The first report on PWN by Kiyohara and Tokushige (1971).

Many researchers were enthusiastic about this work. Mr. T. Kiyohara and Dr. Y.Tokushige found a wood nematode belonging to the genus *Bursaphelenchus* in dead pine trees throughout the Kyushu district, but the nematode was not extracted from healthy trees (*827, 2078*). Finally, it was shown to be a cause of severe pine damage by the following results; (1) *Bursaphelenchus* sp. was extracted from dead pine trees, (2) it was cultured with fungi, (3) a high percentage of trees inoculated with cultured nematode wilted like those in field conditions, (4) the nematode was extracted again from inoculated and wilted trees (*828, 859*). At the same time, *M. alternatus*, one of the pine bark and wood borers, was recognized to be an important insect vector (*1222*).

A conference on controlling pine damage was held at the Government Forest Experiment Station in Tokyo in February of 1971. Results concerning the above-mentioned tests were officially announced (*1410*). These remarkable results stunned many researchers. Dr. Ichinohe, the leading nematode researcher in Japan, closed the conference expressing his admiration as follows:

(1) Since only one nematode had previously been found to kill trees (*Rhadinaphelenchus cocophilus* on *Cocos nucifera*) (*99*), it was hardly thought that *Bursaphelenchus* sp., commonly accepted as a

weak pathogen, could kill trees. (2) Agricultural nematodes rarely killed plants and a strongly pathogenic nematode capable of killing large pine trees had not previously been recorded. (3) Pine trees inoculated with the nematode wilted very soon, (4) There were very few cerambycid vectors of nematodes.

Discovery of the pathogenicity was made by inoculating the nematode without being influenced by prevailing opinion. These studies were on various fields and led to the following PWN research. Results were reconfirmed by many supplementary tests (*435, 881, 1049, 1160, 1469*). PWN was extracted from wilted pine trees in severely damaged forests throughout Japan but not from those in constantly damaged overmature forests (*206*). From these numerous studies it was concluded that severe pine damage was caused by PWN (*593*). Some academic prizes were given to several members of the working group, Mr. T. Kiyohara, Dr. Y. Tokushige, Dr. Y. Mamiya, Dr. K. Morimoto and Mr. N. Enda, for the studies on PWN and JPS. Since PWN became a matter of public concern many explanatory papers were published (*870, 1048, 1051, 1059, 1060, 1069, 1071, 1075, 1214, 1215, 2073~2075, 2079*).

Research of the working group resulted in many new notes on *Rhizina undulata*, tree physiology, soils etc., and came to an end in 1972 (*124, 684, 1448, 1492, 1661, 2324*). A renewed working group on controlling pine damage was started in 1973 and researched the wilt mechanism, biology of insect vectors etc. for three years (*595*), and the results were summarized (*1, 187, 360, 597, 894, 915, 1058, 1151, 1217, 1391, 1412, 1547, 1848, 1999, 2213*). Dr. K. Ito was in charge of these working groups and I have never known such an able leader as he.

10.3. Decision on species name.

The genus *Bursaphelenchus* belongs to the family Aphelenchoididae, Nematoda. *Bursaphelenchus* spp. are often extracted from the galleries of Scolytidae beetles in Europe and the U. S. A. but seldom from Cerambycidae beetles (*1640*).

PWN was first named *Bursaphelenchus lignicolus* N. sp. (*1090*), but was similar to the timber nematode, *Aphelenchoides xylophilus* (*1320, 1801*). Based on the typical morphological characters of original specimens of *B. xylophilus* that were rediscovered in the USDA Nematode Collection, and on genetic crosses among *B. lignicolus* and *B. xylophilus*, it was concluded that they were the same species, *B. xylophilus* (*1323, 1324*). This name change has been explained in detail (*1065, 1068*). There was no difference in reproduction rate between PWN extracted from pine trees in the State of Missouri and those from Saga prefecture in Japan (*962*). Since the disease caused by *B. xylophilus* has been named variously wood–nematode disease of pine, pine wilt disease, pine wilting disease and so on, it was desired to simply name it pine wilt (*2026*). I use the term PWN wilt in this book.

10.4. Morphology.

The PWN is illustrated in Fig. 15 and its morphology has been reported in detail (*1090, 1324*). PWN ultrastructure was observed by SEM–scanning electron microscope (*834, 958*). Since it is difficult to differentiate between PWN and *B. mucronatus* (*1082*), only expert researchers are able to identify them.

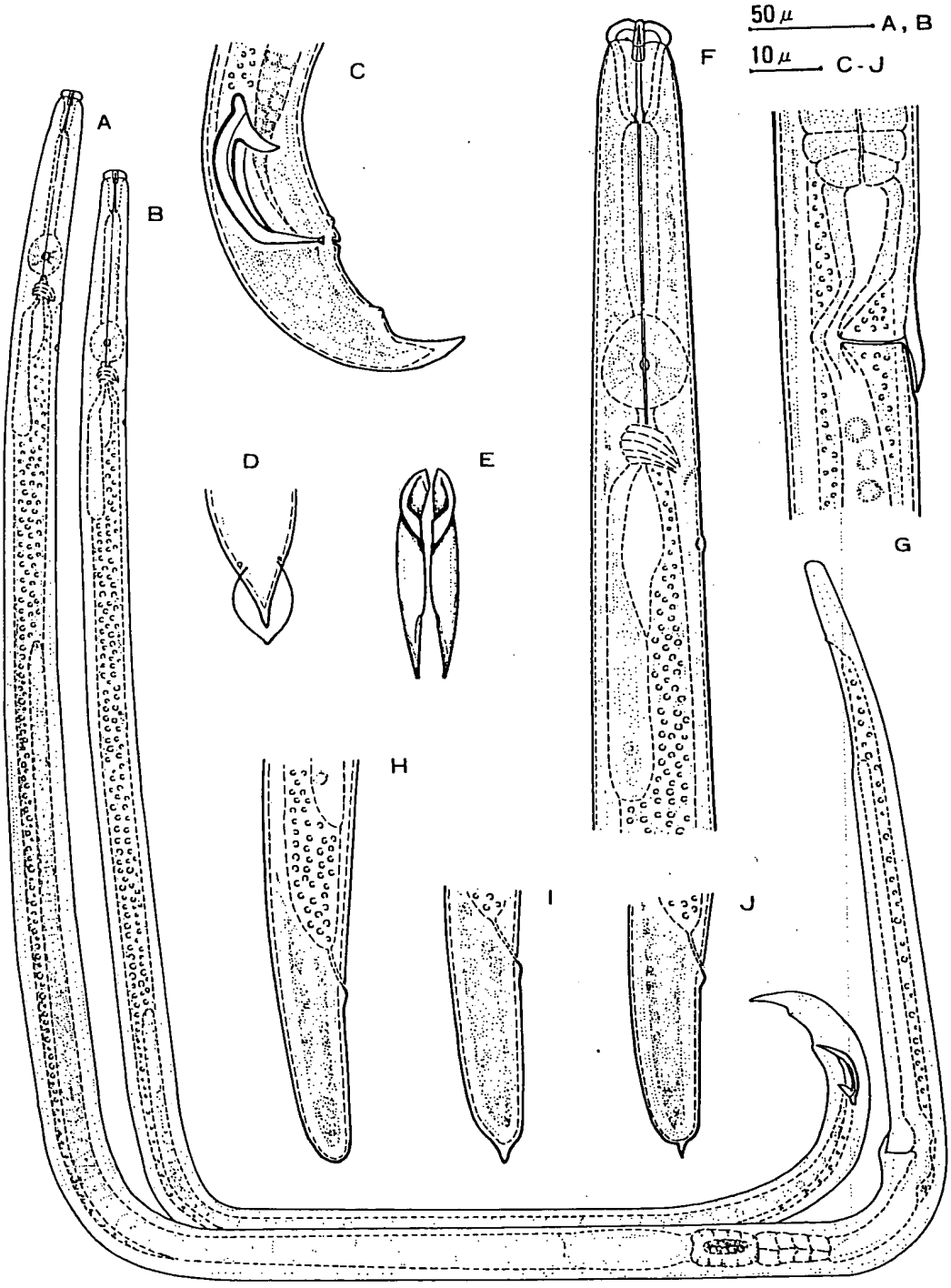


Fig. 15. *Bursaphelenchus xylophilus* n. sp. A. Female. B. Male. C. Male tail. D. Ventral view of male tail, tip with caudal alae. E. Ventral view of spicules. F. Female, anterior portion. G. Female vulva. H–J. Female tail. (*1090*).

Section 11. Biology of PWN

11.1. Host trees in Japan.

The tree species sustaining severe damage are *Pinus densiflora, P. thunbergii* and *P. luchuensis*, which are the main Diploxylon in Japan. PWN and insect vectors in other pine species are detailed in Section 14. I surmise that most Pinaceae are potential host trees for PWN.

11.2. Life history.

Nematodes often have several developmental stages for survival (*569*), and PWN has propagative and dispersal forms (*1053*). Comparison of developmental rates and population growth between PWN and *B. mucronatus* were reported in detail (*291*).

(1) The propagative form.

The propagative form is capable of reproduction under favorable conditions. Dr. Mamiya reported the form as follows (*1053*) :

Eggs took 26–32hr to hatch in water at 25℃. There were four molts, the first in the egg. The second –stage larvae (L2) were placed on fungal mats and began to feed soon after hatching. Feeding was necessary for further development. In the fungal mats of *Botrytis cinerea*, hatched larvae reached the adult stage in 4 days at 25℃, and oviposition took place on the fourth day after hatching. The life history was completed in 12 days at 15℃, in 6 days at 20℃, and in 3 days at 30℃. Development was a little restrained at 33℃. It was theoretically demonstrated that the minimum temperature for development was 9.5℃.

Copulation was necessary for reproduction. In the fungal mats of *B. cinerea* at 25℃, PWN laid an average of 79 eggs (0～216) per female over a 28–day oviposition period, and peak oviposition generally occurred within 4 days after egg–laying commenced (*1085*). On the other hand, an average of 150 eggs was also reported (*962*). Adult females died shortly after oviposition ceased, and the female life span averaged 15 days with a maximum of 32 days (*1085*).

(2) The dispersal form.

The dispersal form occurs under unsuitable conditions such as drying and fasting. In the case of PWN, this is the form suitable for being carried by JPS. The dispersal third–stage larvae (LⅢ) and fourth–stage larvae (LIV, dauerlarvae) occurred abundantly in wilted trees in winter and spring (Fig. 21). In November, proportion of the dispersal third–stage larvae was negatively correlated with PWN density and positively with the wood water content (*302*). In early spring, the dispersal third–stage larvae gathered around JPS pupal chambers and after molting in late spring became the dispersal fourth–stage larvae, entering the bodies of JPS (*1050, 1226*). They molted at temperatures over 15℃ (*1414*). In summer, the dispersal fourth–stage larvae became adults in pine trees soon after being carried by JPS and reproduction then began (*1224, 1414*). Wood tissues of Pinaceae, of *Pinus* spp. and *Larix leptolepis* in particular, hastened the molting of the dispersal fourth–stage larvae (*1072*).

In experiments, the dispersal third–stage larvae occurred in pine logs 55～69 days after PWN inoculation (*2006*). They began to occur after 3 to 5 months on the fungal mats of *B. cinerea* without being subcultured and constituted almost 100% of the surviving nematodes after 10 months (*570*).

The cuticle of dispersal third–stage larvae was the thickest of all stages of the two forms, and the proportion of basal layer (67% of cuticle) of dispersal fourth–stage larvae was the highest (*961*). The external cortical layer was thicker in the dispersal form than in the propagative form (*961*). The gonads of dispersal forms were suppressed compared with that of propagative forms (*568*).

11.3. Food.

Most of the Aphelenchoididae nematodes (to which PWN belongs) are mycetophagous. PWN breaks the hypha cell membrane with its stylet and sips the protoplasm (*2021*). PWN multiplied rapidly on the fungal mats of *B. cinerea* and *Pestalotia* sp. (*162, 859*), rapidly or slowly on those of other plant pathogens and wood decaying fungi (*158*), and more rapidly on those of several fungi other than *B. cinerea* that were isolated from forest soil (*2202, 2203*). Since several fungi such as *Pestalotia* sp. and *Rhizosphaera* sp. were consistently isolated from the sound wood of healthy pine trees and seedlings, it seemed certain that pine trunks and branches were potentially infested with these PWN food fungi (*914, 917, 922*). JPS emerging from dead pines carried fungi such as *Ceratocystis* sp. to pine twigs during maturation feeding together with PWN (*914, 917, 921*).

According to histopathological studies on PWN infested trees PWN occurred mostly in the resin canals and epithelial cells were also damaged (*1090*). It was surmised that PWN sipped cell protoplasm by putting the anterior portion or its full body into cells (*1000*). Therefore it was investigated as to whether PWN could feed on higher plant cells. PWN was successfully cultured on the callus tissues of *Medicago sativa* (alfalfa), *P. densiflora, P. thunbergii* and *Cryptomeria japonica*, and it was thought that PWN could feed on higher-plant cells such as resin cells (*1997, 2013~2016*).

From these results PWN food, such as fungi and cells always seem abundant in its environment.

11.4. Reproduction.

Reproduction in pine trees is detailed in Section 12.5 and 13.4.

According to artificial culture tests of 54 fungi at a constant temperature of 25°C, PWN multiplied rapidly on the fungal mats of *B. cinerea, Pestalotia* sp., *Diaporthe conorum* etc. and most abundantly on *B. cinerea* (*158*). Under constant temperatures PWN multiplied rapidly above 15°C and most abundantly at 25°C on the fungal mats of *B. cinerea*, above 15°C and most abundantly at 30°C on *Pestalotia* sp., above 20°C and most abundantly at 35°C on *Alternaria kikutiana*, and most quickly and abundantly at 25°C on *B. cinerea* (*162*). PWN multiplied more abundantly on the fungal mats of several fungi isolated from forest soil such as *Mortierella* sp., than on those of *B. cinerea* (*2202, 2203*).

By cultivating a single female and male on the fungal mats of *B. cinerea* at a constant temperature of 25°C, PWN multiplied from 2 to 85,000 after 2 weeks and to 489,210 after 3 weeks (*1161*), while production of 263,000 PWN after 15 days was calculated theoretically (*1085*). The growth curve of PWN on the fungal mats of *B. cinerea* could be applied to a logistic curve (*166, 2298*). PWN populations cultivated from the dispersal form did not at first increase as rapidly as those from the propagative form (*811*). Since PWN populations inoculated on PDA culture medium together with *B. cinerea* were several times as abundant as those on the fungal mats alone, it was thought that PWN might multiply more rapidly by selectively feeding on young hyphae (*165*).

Culture media were also examined. Addition of sugars such as glucose to the culture medium increased or decreased PWN population, but PWN multiplied most abundantly on PDA culture medium (*165*). Addition of unsaturated fatty acids such as linoleic and oleic acid to the fungal mats of *B. cinerea* hastened PWN growth and occurrence of the dispersal third-stage larvae, but rarely increased populations (*1079, 1999*). Addition of fatty extracts from JPS larvae and pupae to the fungal mats of *B. cinerea* increased both PWN survival and the numbers of dispersal third-stage larvae if left without subculture (*570*). PWN growth was hastened by addition of benzoic acid, catechol, β-myrcene etc. (*578, 1507, 2145*), and controlled by actidion, 8-hydroxycarvotanacetone etc. (*1506, 1507, 1840*). PWN inoculated into pine logs multiplied under suitable humidity conditions (*160, 370, 827*).

PWN was commonly collected with the Baermann apparatus. More than 90 percent of PWN in PDA culture medium could be collected with the apparatus set up at 20℃ for 24 hours (*1179*). More than 80 percent of PWN and all PWN in wood chips could be collected with the apparatus set up at 15℃ for 24 hours and from 5 to 40℃ for 168 hours (*1179*). Most of the PWN in wood chips could be collected with this apparatus in 24 to 48 hours (*831, 1055*). About 60 to 87 percent of PWN in JPS adults could be collected with the apparatus set up at 25℃ for 48 hours after chopping up the JPS with scissors and grinding them in a mortar (*901*). A suspension without dead PWN could be obtained with the apparatus by setting up once more for 6 hours (*1275*). Since the populations differ according to collection method, it is desirable to collect PWN using the same method when populations are to be compared. I always collect PWN from PDA culture medium, wood chips and chopped JPS using the Baermann apparatus set up at 20℃ for 24 hours.

11.5. Attractants and repellents.

The dispersal third-stage larvae which gather around JPS pupal chambers become the dispersal fourth-stage larvae there and enter the spiracles of JPS pupae or new adults (*1226*). Some experiments were conducted to clarify the factors initiating this PWN behavior.

(1) CO_2.

It is well known that CO_2 attracts some species of insects. Both cultured PWN and the dispersal fourth-stage larvae distributed at random on an agar surface in a petri dish moved toward a source of CO_2 introduced on the agar surface at the center (*1196*). CO_2 released from JPS pupae, especially at emergence, was thus deduced to have an important role in transferring PWN from the chamber wall to JPS body (*1197*).

(2) Unsaturated fatty acids.

Both cultured PWN and the dispersal third-stage larvae distributed at random on an agar surface in a petri dish moved toward the agar surface where unsaturated fatty acids such as palmitoleic, oleic and linoleic acid were placed (*1193*). Since the excretions of JPS fourth instar larvae contained these unsaturated fatty acids, it was suggested that larvae in pupal chambers stained the chamber wall with their excretions and deposited these acids, stimulating PWN aggregation behavior (*1194*). In the oleyl group, 1-monoolein exhibited significant attraction, ethylene glycol monooleate exhibited an activity somewhat lower, and oleic acid and oleyl alcohol were definitely inferior to 1-monoolein (*2081*).

(3) Benzoic acid.

Benzoic acid of low concentration attracted PWN on an agar surface in a petri dish, but at high concentration repelled it (*1500, 1506, 1507*).

(4) Bitter and pungent substances.

According to behavioral response tests of bitter and pungent substances against PWN on an agar surface in a petri dish, PWN was attracted by allyl isothiocyanate, naringenin etc. and repelled by capsaisin, magnesium chloride etc. (*2082*).

(5) 8-hydroxycarvotanacetone.

PWN on an agar surface in a petri dish was repelled by 8-hydroxycarvotanacetone (*1500, 1506, 1507*).

(6) β-myrcene.

According to behavioral response tests of volatile components in *P. densiflora* against PWN in an olfactometer, β-myrcene attracted the propagative form strongly and the dispersal fourth-stage larvae much more strongly (*578, 579*).

(7) Extracts from pine shoots.

The aggregation and invasion of PWN and *B. mucronatus* in shoot segments of *P. thunbergii* and *P. taeda* were considered to be regulated in different ways by host- produced substances. Ethyl ether extracts of shoot segments attracted nematodes, but distilled water extracts of *P. taeda* repelled. Also, the invasion rate into segments was reduced by the distilled water treatment of segments, but was unchanged or moderately increased by the ethyl ether treatment (*289, 290*).

(8) Pheromone.

According to observations of PWN on agar strips in petri dishes, males were only attracted to virgin females and were responsive to female secretions emitted into agar and to volatiles from virgin females. Female attraction by males was also observed and the attraction and mating were caused by different factors (*836, 838, 841*).

11.6. Parasitic fungi and mites.

At present it is difficult to control PWN with natural enemies but the biology of its parasitic fungi and mites has been studied. Biocontrol of agricultural nematodes with natural enemies has been reviewed in detail (*1363*).

(1) Nematode-trapping fungi.

The biology of nematode-trapping fungi in crops and trials of biocontrol using them have been reviewed in detail (*1183, 1996*). Nematode-trapping fungi were also detected from most JPS pupal chambers, and *Dactylella leptospora* and another three species were confirmed as trapping and killing PWN (*1095, 2001, 2002*).

Arthrobotrys ellipsospora, which was detected from the sapwood of dead pines, was also found to selectively trap and kill PWN (*2091, 2295*). When pine seedlings were inoculated with PWN 40 days after spraying the fungus, half the seedlings did not wilt (*1651*). This study should be continued.

(2) Parasites.

There are some brief notes on a parasite, *Harposporium* sp. which was detected from PWN (*2001, 2002*).

(3) Mites.

Mites in the galleries of bark and wood borers have been studied intensively in Europe and the U. S. A. Detailed biology of mites which fed on the eggs and young larvae of Scolytidae was reported often (*769, 1642, 2137*) , and some of these mites also fed on nematodes in galleries (*768, 987, 1015*). Eight species of Mesostigmatid mites were found from the JPS itself and JPS pupal chambers in wilted pine trees (*208, 576, 577*). Throughout Japan, *Dendrolaelaps unispinatus, D. fukikoae* and *Proctolaelaps hystrix* were often collected and their behavior in the chambers was investigated in detail (*2009*).

D. unispinatus, D. fukikoae and *Hypoaspis* sp. fed on PWN and multiplied readily by feeding on a mycetophagous nematode, *Panagrellus* sp. (*210, 2010*). Their feeding and oviposition behavior etc. were investigated in detail (*2010*). *D. unispinatus* was often abundant in JPS carrying a large number of PWN (*208, 209*), but there was no relation between mite and PWN number in JPS (*979, 1809*). *D. unispinatus* was also collected from biennial JPS carrying a small number of PWN (*208, 209*), but it was not clear whether this small number of PWN was caused by mite feeding.

11.7. Miscellaneous notes.

Most of the PWN cholinesterases was present mainly in the central nervous system and was considered to be acetylcholinesterase (*1143*).

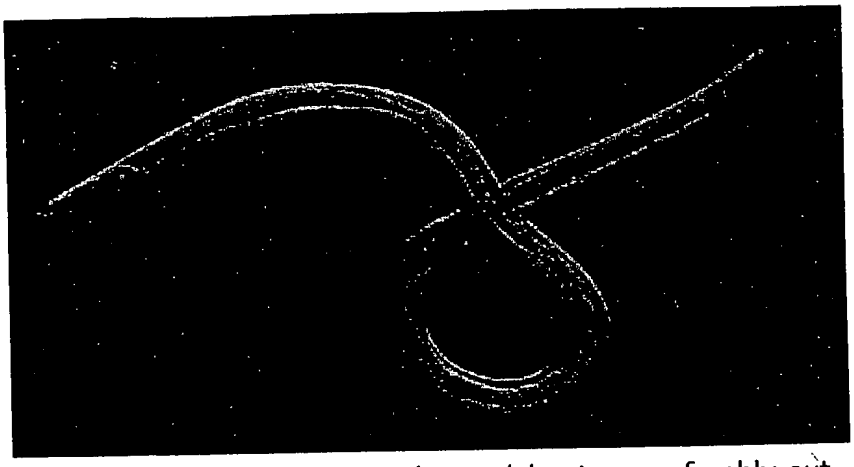
PWN egg shells were found to adhere to polystylol and combine with wheat germ agglutinin (lectin)

more firmly than those of *B. mucronatus* (*258*).

Most PWN became stiff when dipped in hot water extracts of fresh twigs of *P. thunbergii*, but moved again in cold water, or after 72 hours (*1414*).

Two strains of *Phomopsis* species exhibited strong nematocidal activity to PWN in culture liquid, reaching 96.9~99.6% mortality after 48 hours incubation (*2203*).

The Pinewood Nematode in Vermont, USA



Meet the pinewood nematode (*Bursaphelenchus xylophilus*), a microscopic roundworm that is vectored or carried by pine sawyer beetles of the genus *Monochamus*. The nematode infects conifers, especially pines, and is known to occur in the United States, Canada, Mexico, Japan, China, Taiwan, Korea, and, more recently, Portugal. *Bursaphelenchus xylophilus* has a complex and intriguing disease cycle. During the beetle's maturation feeding, the nematode can be vectored to a healthy tree where it can feed on cells in the bark and xylem and cause tree wilt and mortality. This is more likely to occur in Asia, where the nematode is thought to have been introduced around 1900. It can also be vectored to a dying tree or freshly cut timber during the female beetle's oviposition or egg-laying. This is the more likely transmission pathway in North America, where the pinewood nematode is thought to be native. The nematode can also feed on fungi growing in dying or dead trees or in cut timber and thus can be transported in wood products, such as logs, lumber, pallets, crates, wood chips, and furniture, that are not kiln-dried.

See our list of publications on our research of the pinewood nematode.

If you're wondering who studies the pinewood nematode, check our list of current pinewood nematode researchers in the United States.

Publications

Halik, S. and D.R. Bergdahl. 1994. Long-term survival of *Bursaphelenchus xylophilus* in living *Pinus sylvestris* in an established plantation. European Journal of Forest Pathology 24:357-363.
Scots pines (*Pinus sylvestris*) in a 20-year-old plantation in northern Vermont, USA, were inoculated with the pinewood nematode (*Bursaphelenchus xylophilus*) in 1987. To determine how long *B. xylophilus* would survive after inoculation, the trees were periodically observed and sampled for the nematode up to the end of 1993. The nematode was still found in living, healthy-appearing pines 6 years after inoculation.

Bergdahl, D.R. and S. Halik. 1993. Persistence of *Bursaphelenchus xylophilus* in living *Pinus sylvestris*. Phytopathology 83:242 (Abstr.).
A total of 100, 20-year-old Scots pines (*Pinus sylvestris*) were inoculated with a Scots pine isolate of *Bursaphelenchus xylophilus* (pinewood nematode=PWN) to evaluate persistence of the nematode in the host tree. Ten trees were inoculated on each of 10 dates between 6/1 and 9/14, 1987. Two inoculation wounds were made with a drill bit in the main stem of each tree and approximately 30,000 nematodes were inoculated per wound. In addition, 10 trees were inoculated on each of 3 dates with a nematode-free solution. All trees were visually evaluated annually and sampled periodically between 1987 and 1992. *B. xylophilus* was extracted from asymptomatic living trees for up to 5 years after inoculation as well as from dead trees but not from controls. The PWN was most frequently extracted from trees inoculated on 7/7 and 9/14, 1987.

Halik, S. and D.R. Bergdahl. 1992. Survival and infectivity of *Bursaphelenchus xylophilus* in wood chip-soil mixtures. Journal of Nematology 24:495-503.
To determine the effect of soil environment on the life stages and total numbers of *Bursaphelenchus xylophilus*, nematode-infested wood chips alone and mixed with soil were incubated at 12 and 20 C. Nematodes were extracted at 2-week intervals for 12 weeks. Numbers of nematodes and percentage of third-stage dispersal

ırvae were greater at 12 C and in chips without soil. Percentage of juveniles of the propagative cycle was reater at 20 C and in chips with soil. Although *B. xylophilus* survived in chips with soil for 12 weeks, nematode umbers and life stage percentages changed little over time. To determine if *B. xylophilus* was capable of infecting ıounded roots, infested and uninfested chips were mixed with soil in pots with white and Scots pine seedlings. rees were maintained at 20 and 30 C and harvested at mortality or after 12 weeks. Only seedlings treated with ıfested chips contained nematodes. In field experiments, planted seedlings were mulched with infested chips to etermine if nematodes would invade basal stem wounds. Among these trees, Scots pine was more susceptible han white or red pines to infection and mortality.

ergdahl, D.R., S. Halik, J. Tomminen, and H. Akar. 1991. Frequency of infestation of *Monochamus notatus* and *M. scutellatus* by *Bursaphelenchus xylophilus* in Vermont. Phytopathology 81:120 (Abstr.).
\dult *Monochamus notatus* (Mn) and *M. scutellatus* (Ms) were collected from two locations in central and ıorthern Vermont from 6/4–9/1, 1988. On the day of collection, beetles were identified to sex, sectioned and ılaced in distilled water for 24 hours to extract dauerlarvae of *Bursaphelenchus xylophilus* (Bx). There was no lifference in frequency of infestation of the two beetle species by Bx (Mn=51% and Ms=56%) but infested Ms :arried a greater mean number of dauerlarvae (5450 vs 595). Frequency of infestation was independent of sex for :ach beetle species and there was no difference in mean number of dauerlarvae carried between sexes within :ach species of *Monochamus*. Frequency of infestation of male Ms was dependent on time and the mean number ɔf dauerlarvae carried by male Ms appeared to decrease after the first month. There was no difference in 'requency of infestation or mean number of dauerlarvae carried for Ms females.

Tomminen, J., S. Halik and D.R. Bergdahl. 1991. Incubation temperature and time effects on life stages of *Bursaphelenchus xylophilus* in wood chips. Journal of Nematology 23:477–484.
*N*ood chips of Pinus strobus inoculated with *Bursaphelenchus xylophilus* were incubated at 3, 12, 30, or 40 C during intervals of 47, 82, and 130 days to determine the effects of incubation temperature and time on total ıumber of nematodes and occurrence of each life stage. Nematodes did not survive at 40 C; the greatest number ɔf nematodes was maintained at 3 C. The number and percentage of juveniles in the propagative cycle were greatest at 3 C after 47 days, but the percentage was greatest at 30 C after 130 days. More third-stage dispersal larvae, with percentages as high as 85%, were extracted at 3 and 12 C than at 30 C by the end of the study. Dauer larvae were extracted from the chips but percentages never exceeded 5%. The percentage of adults was greater at 30 C than at 3 and 12 C after 82 and 130 days. When a 1-week heat treatment of 30 C was applied to samples at 3 and 12 C, numbers and percentages of adults increased. Percentages of dauer larvae increased very slightly when the heat treatment was applied after 47 days.

Halik, S. and D.R. Bergdahl. 1990. Development of *Bursaphelenchus xylophilus* populations in wood chips with different moisture contents. Journal of Nematology 22:113–118.
Bags of *Pinus strobus* wood chips with moisture contents of 38, 92, 164, and 217% (oven dry weight) were inoculated with *Bursaphelenchus xylophilus* and incubated at 30 C in order to determine the effect of wood moisture on nematode population development. Nematodes were extracted after 2, 4, 8, and 12 weeks. Population levels were greatest in wood chips with a moisture content of 38% and decreased successively with each higher moisture content. In chips with the three lower moisture contents, populations peaked at 2 weeks, but at 217% moisture, they peaked at 8 weeks. By 12 weeks, nematode populations had declined in wood chips with 92 and 164% moisture contents. The fungi most frequently isolated from the wood chips were *Alternaria*, *Fusarium*, *Gliocladium*, *Graphium*, *Penicillium*, *Trichoderma*, and Mucorales.

Halik, S. 1990. Survival of *Bursaphelenchus xylophilus* in wood chips in soil and potential for infesting roots of pine seedlings. M.S. thesis, University of Vermont, Burlington, VT, 64pp.
To determine the effect of soil environment on pinewood nematode life stages and population level, nematode-infested wood chips alone and mixed with soil were incubated at 12 and 20 C. Nematodes were extracted at 2-week intervals for 12 weeks. Nematode population level was greater in chips without soil, and both population level and percentage of dispersal larvae were greater at 12 C. Percentage of propagative stage juveniles was greater in chips with soil. Although nematodes survived for 12 weeks in chips with soil, neither population level nor proportions of life stages changed over time.
To determine if the nematode was capable of infesting wounded roots, infested and uninfested chips were mixed with soil in pots with white and Scots pine seedlings. Trees were maintained at 20 and 30 C and harvested at mortality or after 12 weeks. Planted seedlings were mulched with infested chips to determine if nematodes would

vade basal stem wounds. More seedlings treated with infested chips died and contained nematodes, but there as no difference between temperature effects. Of planted seedlings, Scots pine was more susceptible to festation and mortality than were white or red pines.
o observe the infection process of the pinewood nematode in root tissue, sections of roots of white pine eedlings were wounded and inoculated with nematodes. Inoculated roots were prepared for scanning electron iicroscopy and the wound surfaces scanned for evidence of nematode penetration. To investigate the istological associations of the pinewood nematode in root tissue, infested roots of white pine seedlings were ectioned and stained for light microscopy. Nematodes appeared to enter roots primarily through cortex and hloem, either intercellularly or via resin canals and were observed infesting all woody root tissues. Parenchyma ell contents were granular and stained brown or were completely destroyed.

lergdahl, D.R. 1988. Impact of pinewood nematode on North America: Present and future. Journal of Nematology 0:260–265.
Bursaphelenchus xylophilus, pinewood nematode (PWN), is the most serious pest of pine forests in Japan, but in lorth America its role in pine wilt disease is still being studied. The PWN is known to infest many species of *Pinus*, with *P. nigra*, *P. sylvestris*, and *P. thunbergii* the most susceptible in the eastern United States. Because of :s potential, several European countries (Finland, Norway, and Sweden) and Korea have established embargoes igainst the importation of coniferous wood from regions of the world known to be infested with the PWN. Although the PWN is not considered an economic pest in North American forests, the recent embargoes have stablished an impact on current forest management practices and an economic impact on North American export trade.

Tomminen, J., S. Halik, and D.R. Bergdahl. 1988. Dauerlarvae of *Bursaphelenchus xylophilus* formed in wood chips of *Pinus strobus*. Nematologica 34:298 (Abstr.).
Twenty plastic bags each containing 200 g of wood chips of *Pinus strobus* L. (eastern white pine) were inoculated with an isolate of *Bursaphelenchus xylophilus* (Steiner & Buhrer 1934) Nickle 1970 (pine wood nematode) from that host. All bags were incubated at 30 C for four weeks after which the bags were divided into four treatments and incubated as follows: Treatment 1 was incubated an additional 10 weeks at 30 C. Treatment 2 was incubated an additional 10 wk at 30 C and another 8 wk at 12 C after which 3 bags were extracted. The remaining two bags were extracted after one additional week at 30 C. Temperatures for treatment 3 were gradually reduced during a 3 week period from 30 C to 12 C and then incubated 7 more weeks. Three bags were then sampled and the remaining 2 were extracted after an additional 2 days at 30 C. Incubation temperature for treatment 4 was decreased to 12 C as in treatment 3 but then incubated 8 wk at that temperature. Temperature was further reduced to 3 C and after 8 wk three bags were extracted. The remaining 2 bags were sampled after an additional week at 30 C. To recover the nematodes the wood chips were extracted using a modified version of the Baermann funnel technique. The nematodes were then evaluated to determine the presence of dauerlarvae. These were recovered only from wood chips which had been incubated at either 3 or 12 C followed by 1 week of incubation at 30 C. The two highest percentages of dauerlarvae were 30 and 21 percent from treatment temperatures of 3 and 12 C, respectively.

Halik, S. and D.R. Bergdahl. 1987. Infestation of wounded roots of *Pinus strobus* by *Bursaphelenchus xylophilus* from contaminated wood chips in soil. Phytopathology 77:1615 (Abstr.).
White pine (*Pinus strobus*) wood chips were inoculated with an isolate of *Bursaphelenchus xylophilus* from that host and incubated at 30 C for 8 wks. After incubation, the average wood moisture content (mc) was about 130% based on oven dry weight (ODW) and the nematode population was about 50/g ODW. Uninfested wood chips (130% mc) were used as a control. For each treatment, approximately 150 g of wood chips were mixed with soil in each of 12 one liter pots. Wounds were made at 3 locations on the roots of 24 (12 per treatment) five-year-old white pines by scraping the bark to expose xylem tissue. Seedlings were potted in these chip-soil mixtures and maintained in the greenhouse up to 12 wks at 18–29 C. Seven of 12 seedlings treated with nematode-infested chips wilted and *B. xylophilus* was extracted from roots and stems. Histological studies showed *B. xylophilus* only in tissues of inoculated seedlings.

Bergdahl, D.R. and S. Halik. 1987. The pine wood nematode associated with conifer mortality in the northeastern United States. Pp. 46–49 *in* M.J. Wingfield, ed. Pathogenicity of the pine wood nematode. St. Paul, MN: American Phytopathological Society Press.
Bursaphelenchus xylophilus was first found in the northeastern United States (Vermont) in dead and dying

astern larch, red pine, and Scots pine in October 1979 and has since been found in eastern white pine and in the xotic species Japanese larch and ponderosa pine. The nematode is usually recovered in relatively low numbers om dead or dying trees, thus the primary cause of conifer mortality in Vermont does not appear to be solely the sult of pine wood nematode infestation. The nematode is believed to be one important component of a highly tegrated biological disease complex which includes: the nematode, insect vectors (*Monochamus* spp.), insect ssociates (bark beetles), wood staining fungi (*Ceratocystis* spp.), other pathogenic fungi, and environmental tress factors such as low soil moisture and high temperature. Results of seedling inoculations in a growth hamber have shown that isolates of *B. xylophilus* from either eastern larch or red pine are pathogenic to both osts. Inoculations of potted and planted seedlings in the field have caused limited mortality. Inoculations of larger ees have not resulted in mortality, however inoculated branches of red and Scots pines have displayed some ortality. Histological observations of *B. xylophilus* in red pine have shown nematodes abundant in the longitudinal nd radial resin canals of the xylem and only occasionally present in the bark. In eastern larch, the nematode has ot been observed in the xylem but has been found near the cambium and in the phloem, cortex and resin canals f the outer bark.

lalik, S. and D.R. Bergdahl. 1986. Population dynamics of *Bursaphelenchus xylophilus* in wood chips of *Pinus trobus*. Phytopathology 76:653 (Abstr.).
reshly cut eastern white pine (*Pinus strobus* L.) wood was chipped, placed in plastic bags (325 g ea.) and noculated with an isolate of *Bursaphelenchus xylophilus* (Steiner and Buhrer) Nickle from *P. strobus*. All noculated and uninoculated (control) chips were placed in a growth chamber at 30 C for up to 8 wk. Nematodes vere extracted at 2 wk intervals using a modification of the Baermann funnel technique. Populations of *B. ylophilus* increased about 30X after 8 wk. Histological studies showed juvenile nematodes present in resin canals nd tracheids of wood chips. Wood staining fungi were more abundant on uninoculated chips than on nematode-nfested chips.

Bergdahl, D.R., D.L.K. Smeltzer, and S.S. Halik. 1985. Components of a conifer wilt disease complex in the northeastern United States. Pp. 152-155 *in* V.H. Dropkin, ed. Proceedings of the United States-Japan Seminar: The resistance mechanisms of pines against pine wilt disease. University of Missouri, Columbia, MO.
Mortality of eastern larch has been observed in many areas of the northeastern United States including Maine, New Hampshire, New York and Vermont. Symptoms include a rapid discoloration and wilting of the foliage, followed by death of the tree. This mortality has also been observed to occur sporadically in other conifers ncluding: European larch, red spruce, ponderosa pine, eastern white pine and Scotch pine. Trees naturally nfested with *B. xylophilus* are also commonly infested with bark beetles, blue staining fungi, and the root rotting fungus *Inonotus tomentosus*. The bark beetle *Dendroctonus simplex* is commonly associated with dead and dying arch and the bark beetle *Ips pini*, with pines. *Monochamus scutellatus* is the only pine sawyer beetle that has been trapped from diseased Scotch pine and *M. carolinensis* and *M. notatus* have been trapped from dead white pine. Species of *Verticicladiella*, *Leptographium*, *Pesotum* and *Ceratocystis* have been isolated from blue-stained wood of eastern larch infested with *B. xylophilus*. Another nematode (*Aphelenchoides* sp.) is commonly extracted from conifers showing symptoms of wilt. Seedlings of eastern larch inoculated in a growth chamber with *Aphelenchoides* sp. have shown some wilt and mortality but not as consistently or as rapidly as in *B. xylophilus* inoculations. *Aphelenchoides* sp. are extracted in low numbers near the point of inoculation and histological studies show the nematode in the cambium and bark tissues.

Bergdahl, D.R. and D.L.K. Smeltzer. 1981. Histological observations of *Bursaphelenchus xylophilus* in symptomatic tissues of *Larix laricina* and *Pinus resinosa*. Phytopathology 72:257 (Abstr.).
Eastern larch (*Larix laricina*) and red pine (*Pinus resinosa*) were inoculated in the greenhouse with the pine wood nematode (*Bursaphelenchus xylophilus*). Symptomatic tissues were excised, fixed and stored in FAA before sectioning on a freezing microtome. Sections of wood were stained with safranin/cotton blue in glycerine/alcohol before examination for nematodes. Nematode populations were higher in tissues of red pine than in eastern larch. In red pine, nemas were abundant in longitudinal and radial resin canals of the xylem, but only occasionally observed in tissues of the bark. Nemas in eastern larch were not observed in the xylem tissues, but were found in the cambial region and in the phloem, cortex and resin canals of the bark.

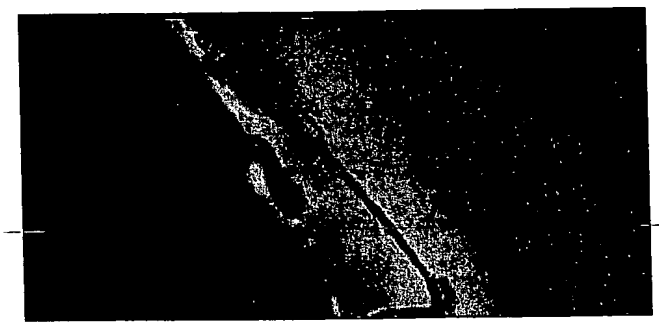
Conifer Hosts of the Pinewood Nematode Found in Vermont

- Eastern white pine (*Pinus strobus*)
- Ponderosa pine (*Pinus ponderosa*)
- Red pine (*Pinus resinosa*)
- Scots pine (*Pinus sylvestris*)
- Eastern larch (*Larix laricina*)
- Japanese larch (*Larix leptolepis*)

Pine Sawyer Vectors of the Pinewood Nematode Found in Vermont

Pine sawyers are long-horned beetles of the genus *Monochamus* in the Cerambycidae family. The larvae are called sawyers because of the the noise they make while feeding in a log or stem. "Long-horned" refers to the adult beetle's antennae which, on the males, can be twice the length of the body.

Adult female beetles lay eggs in slits chewed in the bark of freshly cut, dying or stressed trees in the summer. Larvae hatch and bore into the cambium where they feed before tunneling deep into the wood. They chew oval-shaped galleries through which they push shavings back out to the surface. The larvae bore straight into the heartwood, then make a U-turn and head back out. Usually, one or two winters are spent in the wood as larvae and during the spring, the larvae pupate near the surface and adults emerge in June and July through round exit holes. Adults feed for a short time on needles and the tender bark of branches.



Monochamus scutellatus (White-spotted Sawyer) has been found emerging from dead Scots pine in Vermont. This sawyer is found from Newfoundland to North Carolina and west to Minnesota and north to Alaska. Its favorite host is eastern white pine but it will also breed in red and jack pine, balsam fir, white, black, and red spruce and larch. The adult is shiny black with a white spot or scutellum at the base of the elytra or outer wings. Females often have elytra mottled with white spots. The beetle is 15-30 mm long.

Monochamus notatus (Northeastern Sawyer) has been found emerging from dead eastern white pine in Vermont. This sawyer is found from eastern Canada and the northeastern United States to the Lake States. Its hosts include eastern white pine, balsam fir and red spruce. This can be a very large beetle and is 18-35 mm long. It is grayish- or reddish-brown mottled with white and dark brown spots or bands. The female's head is greatly elongated and flattened.

Monochamus carolinensis (Pine Sawyer) has been found emerging from dead eastern white pine and Norway spruce in Vermont. This sawyer's range extends further south than those of *M. notatus* and *M. scutellatus*. It prefers pines and is 13-22 mm in length. The adult is reddish brown with yellow, white and dark brown spots on the elytra.

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Pine Wood Nematode

Ornamental Disease Information Note 6
R.K. Jones, Extension Plant Pathologist
J.R. Baker, Extension Entomologist

[General Information] [Susceptibility of Trees] [Symptoms] [Spread] [Diagnosis] [Control]
[Back to Ornamental Disease Notes] [Other Resources]

General Information

The pine wood nematode or pine wilt nematode (*Bursaphelenchus xylophilis*) has been causing widespread losses to pines in Japan since the early 1900's. This nematode was first identified in the United States in Missouri in 1979. It has now been found in numerous mid-western and eastern states including North Carolina. A survey has shown this nematode to be widely distributed over much, if not all, of North Carolina.

Older trees appear to be more susceptible than young trees. The nematode generally does not attack pines less than 5 or 6 years old. Scots pine Christmas trees, 7-10 years old are being severely damaged in the mid-western states by this nematode.

Recent surveys have found the nematode in *Pinus serotina* (pond pine), two species of larch, one species of spruce (*Picea glauca*) and two species of cedar (*Cedrus deodara* and *C. atlantica*). More research must be done to determine how damaging the nematode will be to these plants. The most serious damage due to the pine wood nematode North Carolina at this time is to Japanese black pine planted along the Atlantic coast.

Susceptibility of Trees to the Pine Wood Nematode

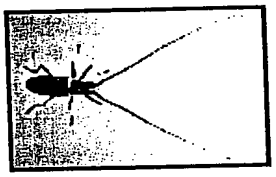
Common Name	Scientific Name	Susceptibility
Atlas cedar	*Cedrus atlantica*	?
'strian pine	*Pinus nigra*	High
Cluster pine	*Pinus pinaster*	High
Deodara cedar	*Cedrus deodara*	?
Jack pine	*Pinus banksiana*	Resistant
Longleaf pine	*Pinus palustris*	Resistant
Japanese black pine	*Pinus thunbergii*	High
Larch	*Larix spp.*	?
Japanese red pine	*Pinus densiflora*	High
Loblolly pine	*Pinus taeda*	High
Mugo pine	*Pinus mugo*	Susceptible
Pitch pine	*Pinus rigida*	Resistant

Pond pine	*Pinus serotina*	?
Scots pine	*Pinus sylvestris*	Moderate
Shortleaf pine	*Pinus echinata*	Resistant
Slash pine	*Pinus caribaea*	Resistant
Slash pine	*Pinus elliottii*	Resistant
Table mountain pine	*Pinus pungens*	Resistant
Virginia pine	*Pinus virginiana*	Moderate
White pine	*Pinus strobus*	Resistant
White spruce	*Picea glauca*	?

Symptoms

The first symptom of the pine wood nematode disease is a general wilt of the needles. As the disease progresses, a yellowing of needles appears, followed by browning and death of the entire tree. Susceptible pine species may die within 30-90 days after the first visible symptoms (longer for more resistant species). The disease can also kill individual branches in a tree. These symptoms may be easily confused with those of several bark beetles, *Fomes annosus* root rot, etc.

Spread



Longhorned beetles in the genus *Monochamus* have been shown to transmit pine wood nematodes. These beetles are known as sawyers. The southern pine sawyer, *Monochamus titillator*, is one of our most common sawyer. It has been observed that sawyers generally infest trees which have been recently killed or trees that are under stress. These beetles are called sawyers because the larvae make a loud chewing noise as they feed. The larvae bore into the wood and degrade the value of the wood for lumber. The larvae are long, white grubs with no noticeable legs. Adult sawyers emerge mostly in April and May, but they are active throughout the summer and even in warm spells during winter.

Diagnosis

To confirm the involvement of pine wood nematode as the cause of dying pines, it is necessary to recover them from diseased wood. This can be done in the laboratory from symptomatic branches or increment borings from the trunk. Do not allow the branches or borings to dry out or get too hot. Submit them as quickly as possible for examination. Check with your local county Extension agent for more information.

Control

The control of pine wood nematodes involves quickly removing diseased trees. The wood should be burned, buried, or debarked. Grow pine species well adapted to your area. In the long term, resistant pines should be selected. Christmas trees and nursery stock which cannot be irrigated during prolonged droughts can be protected from borers such as sawyers by spraying them with lindane.

Since this pest is thought to have been present in the United States for a very long time, and the insects that spread it do not aggressively attack healthy trees, one should not become overly alarmed about pine wood nematode on healthy pines.

Other Resources

DIN006 – Pine Wood Nematode

- Back to Ornamental Disease Notes
- Plant Disease Information Notes Home Page
- Horticulture Information Leaflets Home Page
- HIL-603 Using Pines in the Landscape or PDF version of HIL-603
- HIL-606 Plants for Seashore Conditions
- HIL-638 Large Trees for North Carolina or PDF version of HIL-638
- North Carolina Insect Notes
- North Carolina Agricultural Chemicals Manual
- NCCES Educational Resources

For assistance with a specific problem, contact your local North Carolina Cooperative Extension Service personnel.

[Top of Page]

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Web page last updated Dec. 2000 by A.V. Lemay.

EXHIBIT B

EXPERIMENT REPORT

1. Purpose of The Experiment

To gain longitudinal set recovery of the compressed lumber, which had been permanently compressed by the method disclosed in PCT/JP00/06861.

2. Experimenters

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(2) Name: Yorikuni Shibuya
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3. Place of The Experiment

Engineering Department of Shinshu University
17-1, Wakasato 4-chome, Nagano City, Nagano Prefecture, Japan

4. Period of The Experiment

July 20 – August 31, 2004

5. Explanation of The Experiment

(1) Summary of The Experiment

In Fig. 1, air-dried lumber 10, which has thickness T_0 and prescribed length, was compressed. The thickness of the compressed lumber 12 was T_1. Then, the lumber 12 was cut from one end in the longitudinal direction at regular separations, so that a plurality of test piece having thickness of T_1 were prepared.

Successively, the test piece 12a, which was a distance L away from the one end of the lumber 12, was soaked in boiled water for a prescribed time, then air-dried. Thickness T_2 of the air-dried test piece 12a was measured, and Set recovery E was calculated with the following formula:

$$E=[(T_2-T_1)/(T_0-T_1)]\times 100$$

(2) Preparing Compressed Lumber

Cedar lumber (length: 300 mm, thickness: 20 mm, moisture content: 10.0 wt%) was compressed in the compressing die disclosed in Fig. 1 of PCT/JP00/06861. Compressibility was 70.4 %.

The compressed state of the compressed lumber was maintained in the compressing die 14 without preheating, and a longitudinal end of the compressed lumber was closed by a closing member. Then, the compressed lumber was heated in a furnace at 180℃ for 120 minutes. After the heating step, the compressing die 14 accommodating the lumber was taken out from the furnace and air-cooled. The compressed lumber was taken out from the cooled die 14. The compressed lumber was

slightly stained in black (see the attached drawing of Fig. 2).

(3) Set recovery

The compressed lumber shown in Fig. 2 was cut from one end in the longitudinal direction at regular separations, so that a plurality of test piece having thickness of 6 mm were prepared.

The test pieces were soaked in boiled water for 60 minutes, then air-dried. Then, thickness of the air-dried test pieces were measured, and set recovery thereof were calculated. The air-dried test piece was shown in Fig. 4.

The lumber not compressed, the compressed lumber and the test piece cut from the compressed lumber are shown in Fig. 5A. The thickness of the lumber before compression is shown in Fig. 5B; the thickness of the test piece before boiling is shown in Fig. 5C; the thickness test piece, which was air-dried after boiling, is shown in Fig. 5D.

The Set recovery of the test pieces with respect to distances from the one end of the compressed lumber are shown in Fig. 6. In a graph of Fig. 6, the horizontal axis indicates the distance from the one end of the compressed lumber; the vertical axis indicates the Set recovery of the test pieces.

According to Fig. 6, variation of the Set recovery was not observed in the longitudinal direction of the compressed lumber, and the compressed lumber had high dimension-stability.

(4) Sectional Micrographs of Cedar Plate

A sectional micrograph of the cedar plate not compressed is shown in Fig. 7A. In Fig. 7A, a part including large cells is earlywood part; a part including small cells is a latewood part.

A sectional micrograph of the compressed cedar plate is shown in Fig. 7B. In Fig. 7B, the earlywood part is mainly compressed. Namely, cells in the earlywood part were mainly compressed and density of the earlywood part was increased by the compression process.

6. Conclusion

In the experiment, the cedar plate was compressed so that the density of the earlywood part of the cedar plate was increased, then the cedar plate was heated with maintaining the high density state. With this method, even in the end portions, the cedar plate could be heated in a state of holding enough amount of moisture, so that the end portions of the cedar plate were sufficiently compressed and their shapes were sufficiently fixed as well as the center portion thereof.

Therefore, variation of the Set recovery was not observed in the longitudinal direction of the compressed lumber produced by the present experiment, so that the compressed lumber had high dimension-stability.

FIG.1

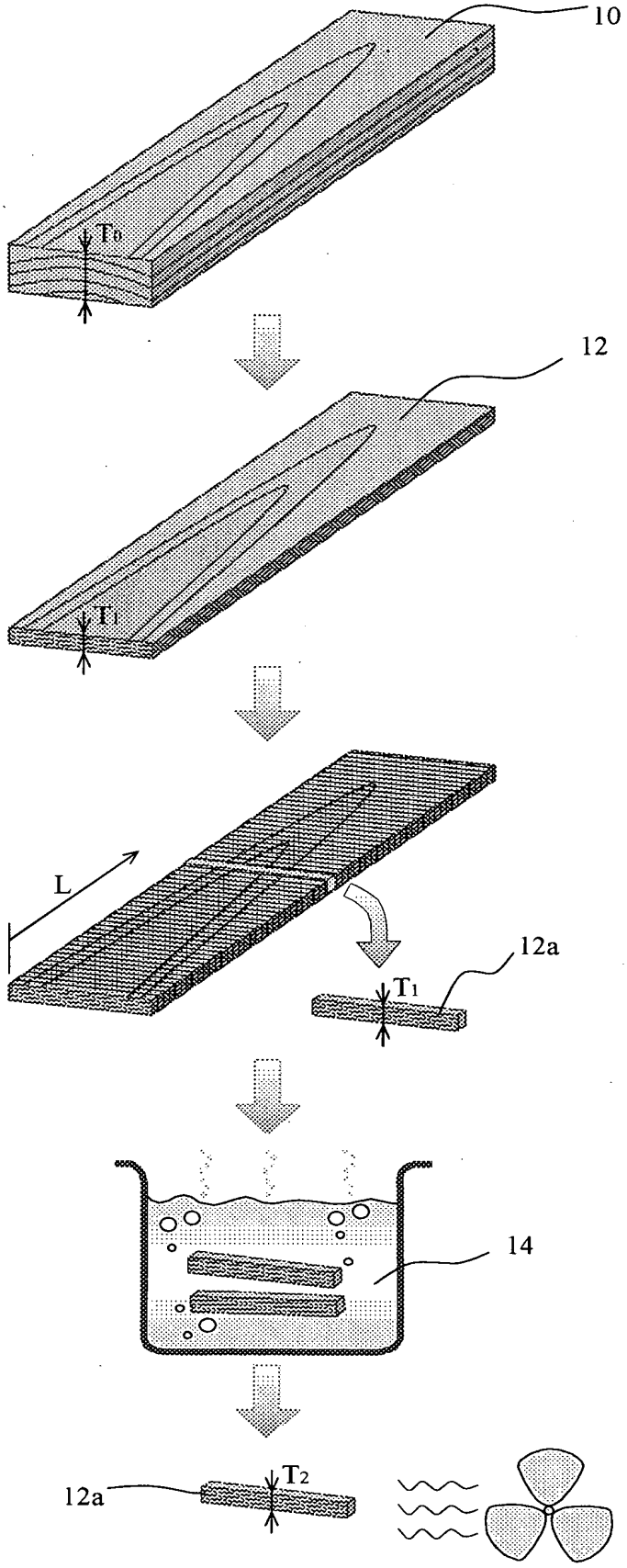


FIG.2

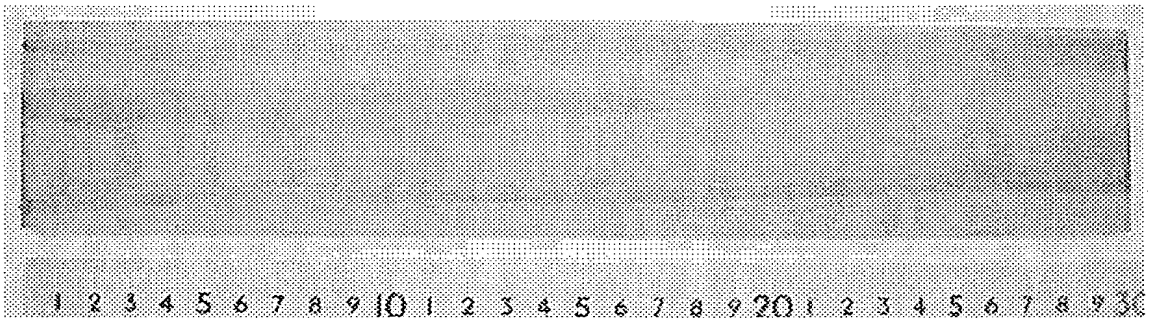


FIG.3

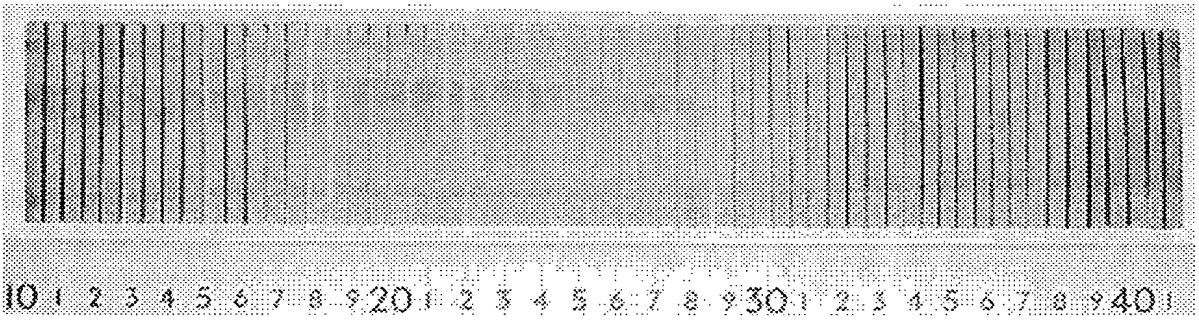


FIG.4

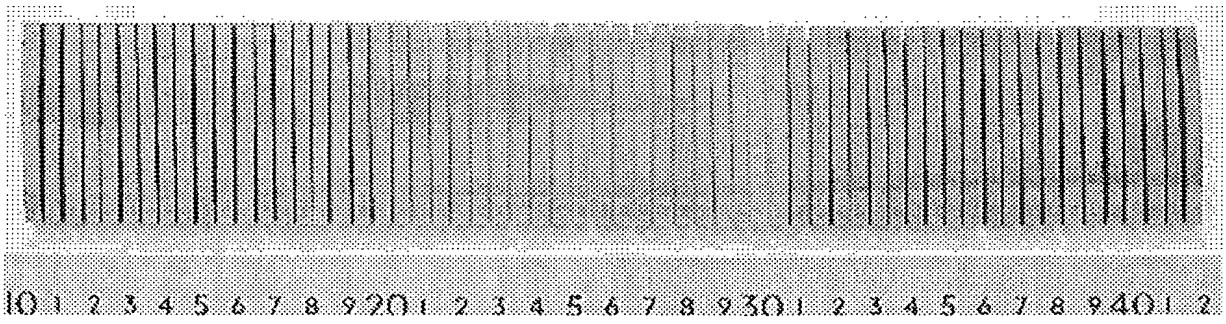


FIG5A

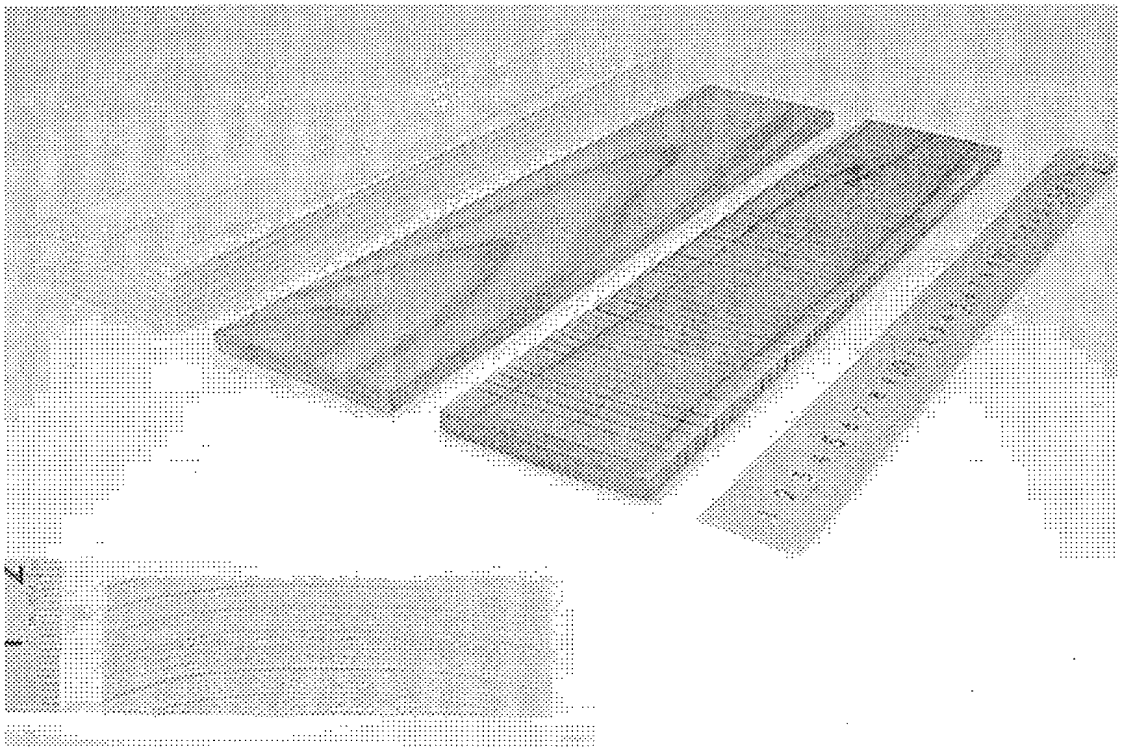


FIG5B

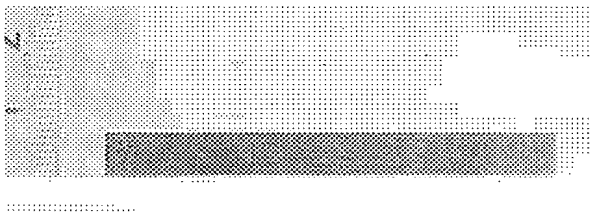


FIG5C

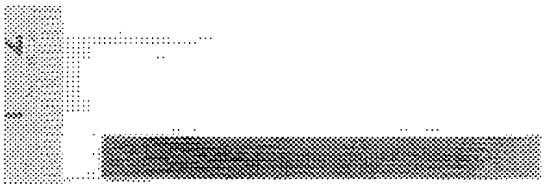


FIG5D

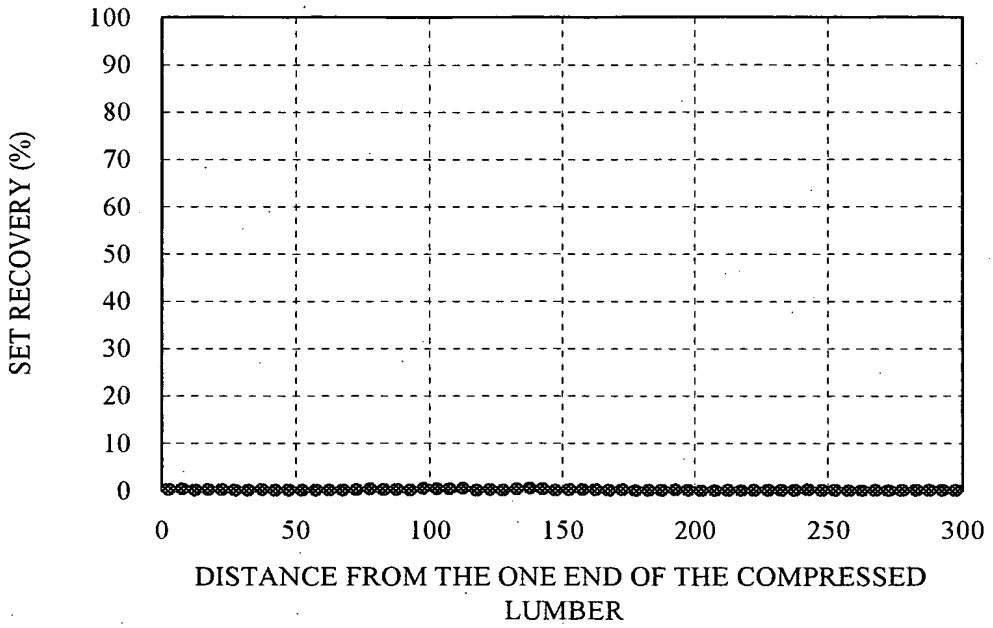

100
90
80
70
60
50
40
30
20
10
0
SET RECOVERY (%)
0
50
100
150
200
250
300
DISTANCE FROM THE ONE END OF THE COMPRESSED LUMBER

FIG. 6

FIG.7A

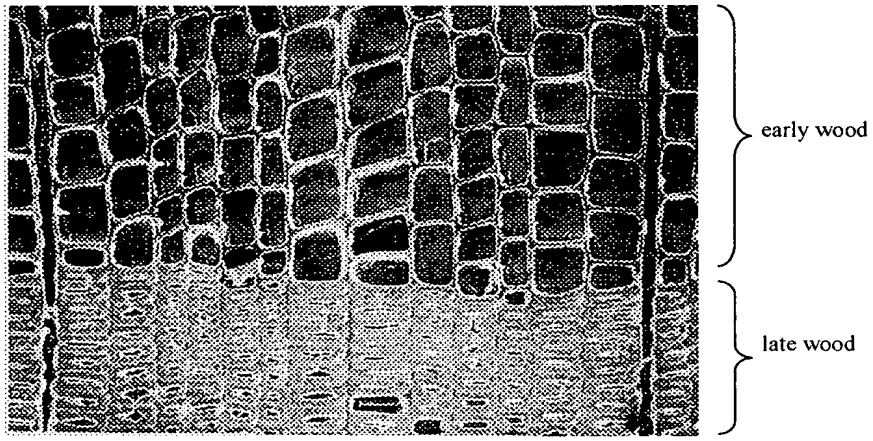


FIG.7B

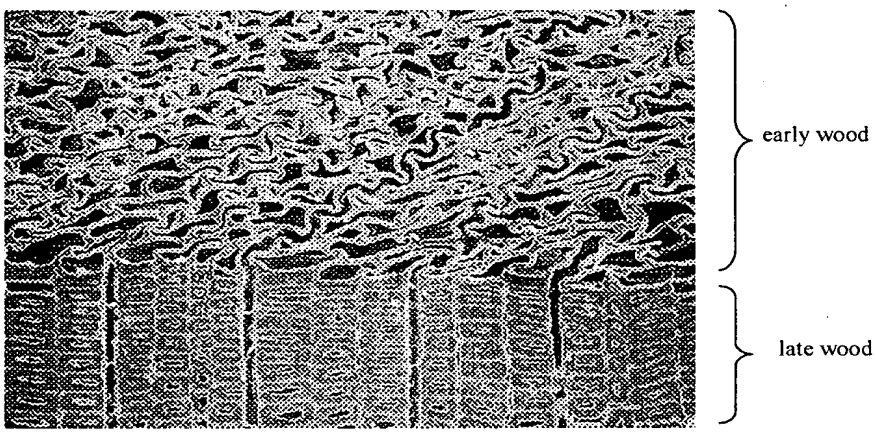
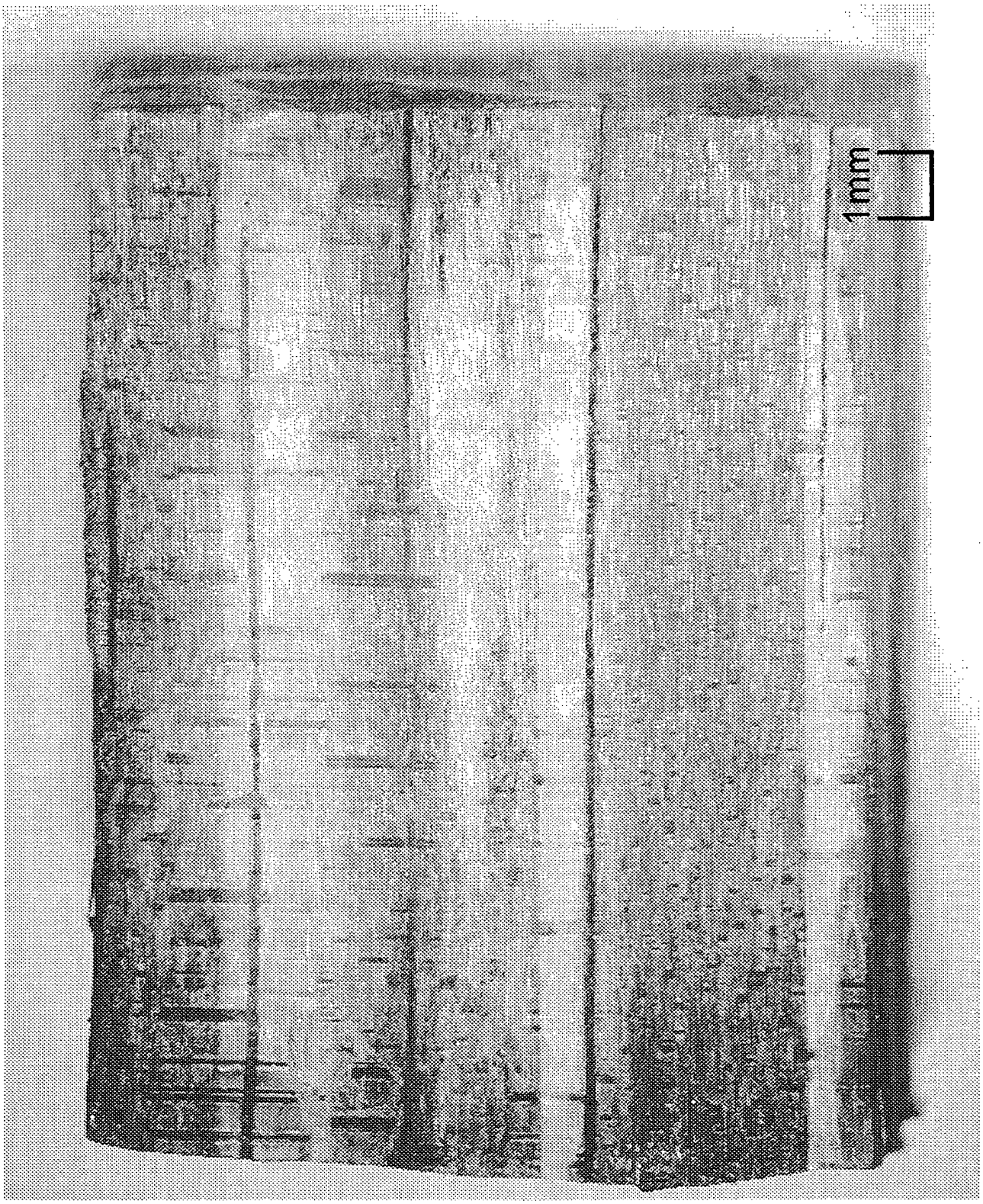


EXHIBIT C



WHOLE

Mechanics of Wood and Wood Composites

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ducts. Hardwoods frequently possess a large number of cell types and hence manifest a somewhat more complex structure than softwoods. Hardwoods grown in the tropics frequently exhibit an unusually complex cellular structure.

1.4.3 Growth Rings

The layered arrangement of the cells called *annual increments*, or more commonly *growth rings*, provides an interesting and important level of organization

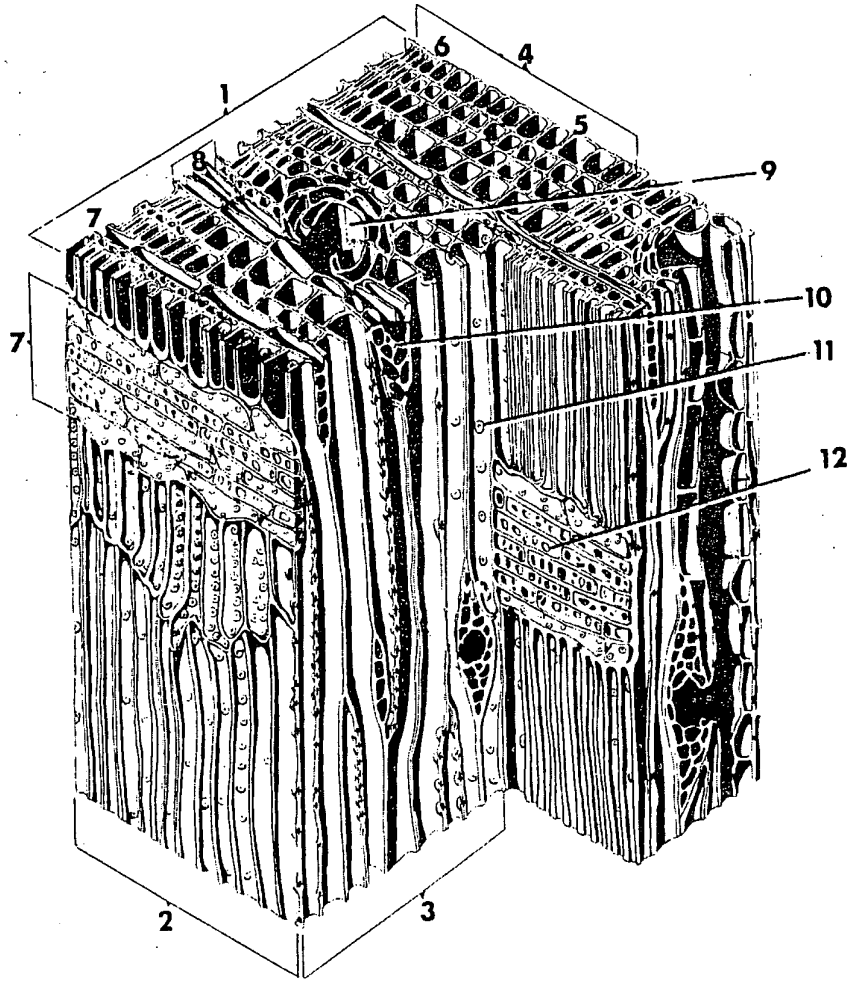


Fig. 1.9. Cellular structure of a softwood: (1) cross section, (2) radial section, (3) tangential section, (4) growth ring, (5) earlywood, (6) latewood, (7) wood ray, (8) fusiform ray, (9) vertical resin duct, (10) horizontal resin duct, (11) bordered pit, (12) simple pit. (Courtesy A. N. Foulger [9].)

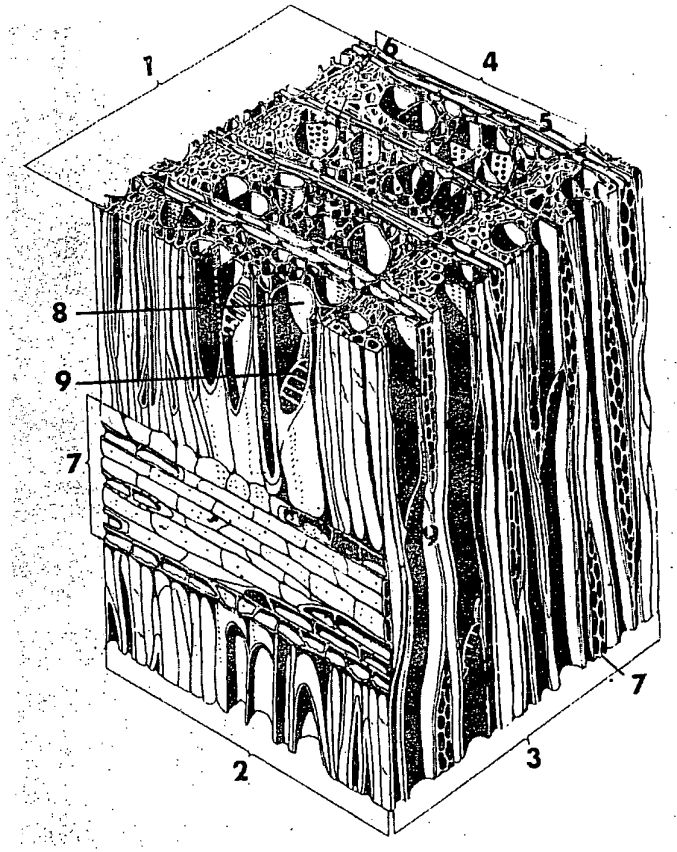


Fig. 1.10. Cellular structure of a hardwood: (1) cross section, (2) radial section, (3) tangential section, (4) growth ring, (5) earlywood, (6) latewood, (7) wood ray, (8) vessel, (9) perforation. (Courtesy A. N. Foulger [9].)

in wood. Wood grown in a temperate climate nearly always produces one growth ring each year. A tropical hardwood may, on the other hand, produce more than one increment in a year in response to alternating wet and dry growing seasons. Typically, a growth ring consists of two distinct parts. The wood formed early in the growing season is light in weight with large cell cavities and is called *earlywood* or *springwood*. The primary function of earlywood in the living tree appears to be the conduction of fluids. The portion of the growth ring which is denser, darker in color, and has smaller cell cavities is called *latewood* or *summerwood*. Because of the increased amount of cell wall substance latewood has a dominant influence on some of the mechanical properties of wood.

tabulated data specific gravity is frequently used to express the relative weight per unit volume of various substances. The weight density of water is used as the basis for such comparisons.

Accordingly the specific gravity D is defined as

$$D = w/w_w, \tag{1.6}$$

where w_w = weight density of water.

Substituting Eq. (1.5) into Eq. (1.6) gives

$$D = \frac{m/V}{m_w/V_w}, \tag{1.7}$$

where

V_w = a given volume of water
m_w = mass of the water volume V_w.

Setting the volume of the substance V to the volume of the water V_w, Eq. (1.7) simplifies to

$$D = m/m_w. \tag{1.8}$$

Thus, specific gravity is the mass (or weight) of a body divided by the mass (or weight) of an equal volume of water. This property is independent of all gravitational forces and therefore is a constant.

Because the mass density of water in the cgs metric system is unity, the numerical values of mass density and specific gravity are of the same magnitude. However, this feature is not true in English units, where the mass density of water is 62.4 slugs/ft^3. Since the specific gravity itself is a dimensionless property it is usable in both measurement systems. Consequently, it will be used almost exclusively throughout this book.

1.6.5 Moisture Content

During the formation of and throughout the life cycle of a woody cell a large amount of water is present. Furthermore, because of the hygroscopic nature of most chemicals in wood, moisture is retained even after the cell is dead. The amount of water present in wood significantly modifies its physical properties. Therefore, a knowledge of the moisture content of wood is particularly important when a physical property is specified. Moisture content is nearly always expressed as a percentage of the oven-dry weight of wood. Oven-dry weight is

obtained by drying in an oven set at 100–105°C until constant weight is attained. Although other methods are sometimes used to establish oven-dry weight, drying to constant weight is the most widely accepted. Presumably, a constant weight free of absorbed moisture can be established using a knowledge of weight before and after oven drying:

$$\mu = \frac{W_w}{W_o} = \frac{W_a - W_o}{W_o} \tag{1.9}$$

where

μ = fractional moisture content
W_w = weight of water of the wood sample
W_o = oven-dry weight of wood sample
W_a = weight of sample prior to drying,

or

$$M = 100\mu = 100\frac{W_a - W_o}{W_o}, \tag{1.10}$$

where M is the moisture content expressed in percent.

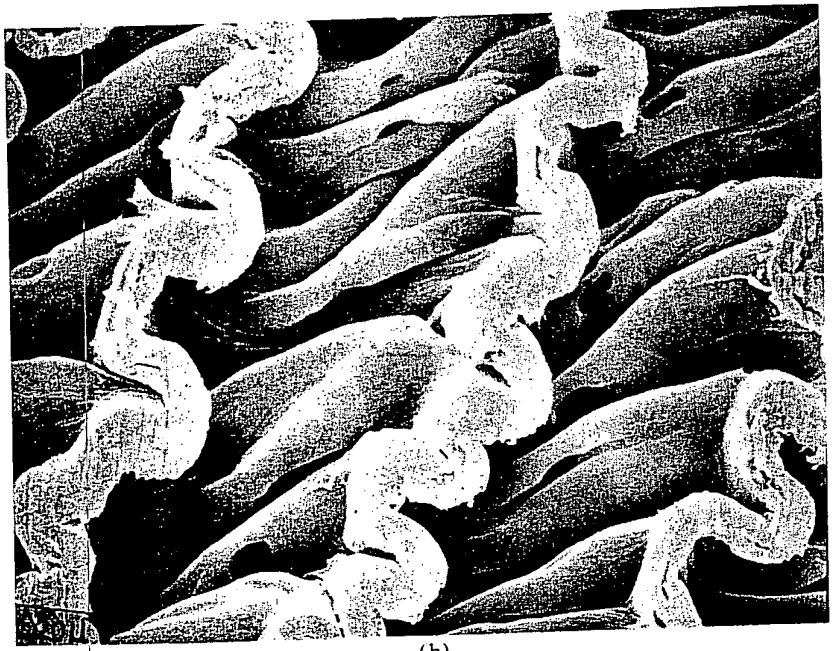
For some materials, a pulp slurry for example, moisture content is expressed using as a basis total weight including the weight of water. Further, the solid content s_a of the slurry is expressed as

$$s_a = 1 - \mu_a = W_o/W_a \tag{1.11}$$

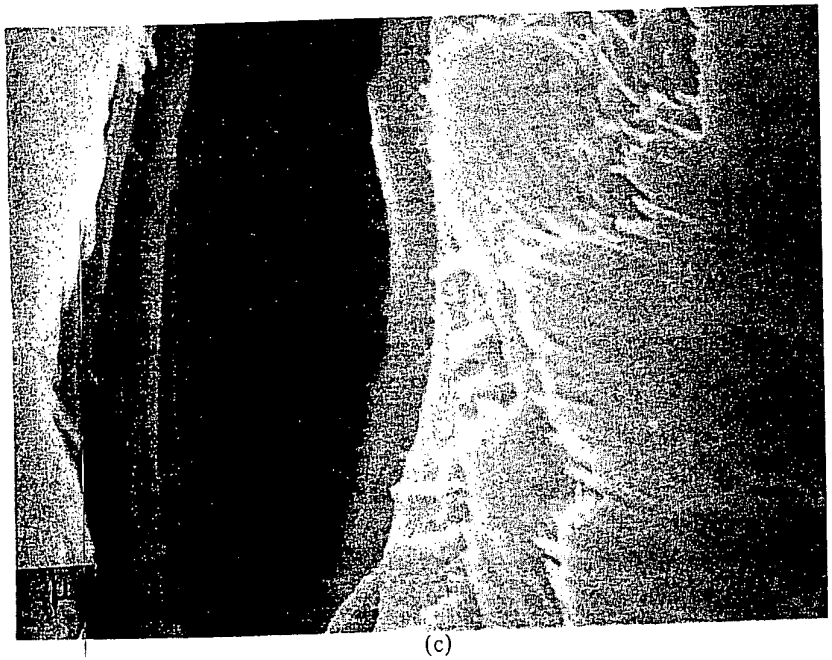
where μ_a is the moisture content of the slurry.

Fiber saturation point M_f is defined as the amount of water required for saturation of the cell wall but with no free water present in the cell lumen. Absorbed moisture is particularly important, as it modifies the mechanical properties of composites, while free water, unless frozen, has no significant effect on physical properties.

The fiber saturation point varies from species to species. Since extractives occupy spaces usually available for water in the cell wall a high extractive content is accompanied by a low fiber saturation point. Conversely, species with low extractive content sustain a higher fiber saturation point than those with high extractive content. For example, the fiber saturation point of white spruce, a wood with a low level of extractives, is 30%, while that for western redcedar, which possesses a high extractive content, is only 22%. The fiber saturation point of most woods grown in temperate regions of the world ranges from 20 to



(b)



(c)

Fig. 7.11. (*Continued*)

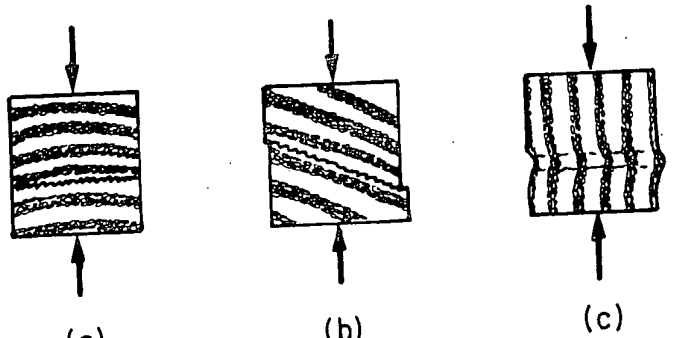


Fig. 7.12. Failure types of clear wood in compression perpendicular to grain: (a) crushing of an earlywood zone, (b) shearing along a growth ring, (c) buckling of the growth rings.

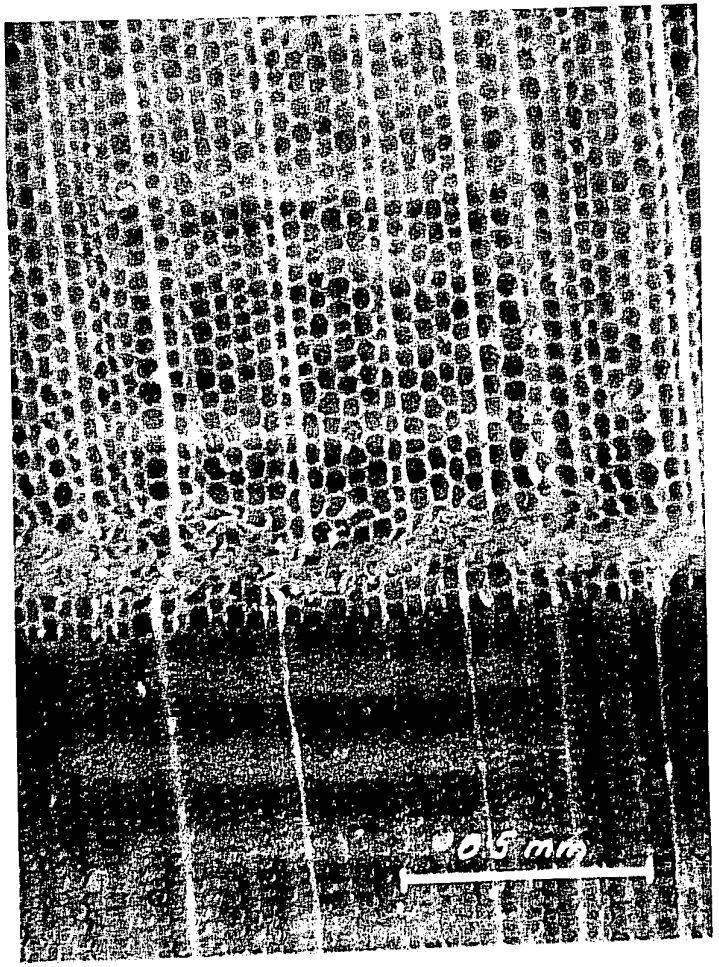


Fig. 7.13. Failure of Douglas-fir in radial compression.

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TO
Frederick F. Wangaard
Teacher, researcher and colleague

EXHIBIT E

[木材学会誌 Vol. 44, No. 6, p. 410-416 (1998) (一般論文)]

高周波加熱による圧縮木材の寸法安定化*1

井上雅文*2, 児玉順一*3, 山本康二*3, 則元 京*2

Dimensional Stabilization of Compressed Wood Using High-Frequency Heating*1

Masafumi INOUE*2, Junichi KODAMA*3,
Yasuji YAMAMOTO*3 and Misato NORIMOTO*2

The dimensional stabilities to moisture and heat for compressed wood with a thickness of 30 mm which was manufactured by a hot press equipped with a radio-frequency generator were investigated. The compressive deformation was fixed in a short time by high-frequency heating during hot pressing. Greater set recovery was observed at 3-5 cm from the longitudinal end, regardless of the length of specimens. However, the set fixation for useful application could be obtained in the central portion of specimens. Moreover, greater dimensional stability could be achieved by increasing the compression set, restraining the edges, and enhancing the compression set at the longitudinal end of specimens during compressing. On the other hand, no effect of the treatment on the fixation of compressive deformation could be found for the dry specimens.

The mechanisms of fixation in compressive deformation using high-frequency heating are as follows: when wood is heated in a hot plate, the steam generated inside the wood is forced out through both the end grains owing to the high internal pressure, resulting in the reduction of the moisture content of the wood. However, when wood is heated by mean of high-power, it is possible to heat the wood to the high temperature of 180-200 °C, while maintaining a high moisture content and high pressure within the wood, resulting in the quick fixation of the compressive deformation of the wood.

Keywords: high frequency heating, compressed wood, set recovery, dimensional stabilization.

高周波誘電加熱を併用して熱板圧締することにより，短時間に，寸法安定性に優れた圧縮木材(仕上がり厚さが30 mm)が得られた。この場合，繊維方向長さによらず，木口付近 3～5 cm の範囲では，若干高い変形回復が認められたが，中央付近では，実用上十分な寸法安定性が確認された。さらに，圧縮率の増加，木口および側面を拘束することにより，回復度は材全体にわたり低い値で安定した。一方，全乾状態の試験片では，本処理の効果は全く認められなかった。

高周波加熱によって圧縮変形が固定される原理は，以下のように考えられた。開放状態で木材を熱板加熱すると，材内部に発生した水蒸気は，材内部圧力上昇に従い木口から外部へ噴出するため材は乾燥する。ところが，圧密状態の木材に高周波エネルギーを急激に印加することにより，木材中の水分が蒸発するまでに，木材内部を固定処理可能な温度（180～200°C）に昇温させることが可能となる。この時，木材内部は，高温，高圧，高含水率状態に保たれるため，密閉熱処理と同様の原理で，変形が短時間に固定される。

*1 Received February 26, 1998; accepted May 27, 1998. 本報の一部は，第47回日本木材学会大会（1997年 4 月，高知）において発表した。

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1. 緒　　言

前報[1]では，木材中の含有水分に着目し，ホットプレス機を用いた簡便な処理によって，短時間で均一に圧縮変形を永久固定する新しい加工方法を提案した。これは，木材サンプルの周囲を治具によって密閉し，木材の含有水分を閉じこめて行う密閉熱処理法である。例えば，180°Cで加熱する場合，吸水，煮沸回復に対し，それぞれ，2，8分間の処理で変形が固定される。しかし，これらは圧縮試験片の仕上がり厚さ，すなわち加熱時の熱板間距離が5 mmでの結果である。住宅用造作材や家具用材など，製品の用途によっては，大断面部材(厚さが20～40 mm)が要求される場合がある。木材は熱伝導率が低いため，熱板から木材への熱伝達によって大断面木材を加熱する場合，厚さ方向に温度ムラが生じやすい。木材の中心部が所定の温度（180～200°C）に到達するためには長時間を要し，その際，表層部付近は過度の処理によって強度性能が劣化するなどの不都合が生じる。さらに，密閉熱処理法では，パンクを防止するため加工材を冷却してから取り出す必要がある。現状ではプレス定盤の加熱，冷却を繰り返しているが，これに要する時間が長く，コストも大きい。そのため，実大サイズの圧縮木材の製造において，木質部の加熱処理を効率よく行うには，加熱効率の高い高周波誘電加熱の併用が有効であると考えられる。高周波誘電加熱とは，高周波エネルギーの電界作用によって，被加熱体に原子や分子レベルでの電位的な運動を起こさせることで，物質内部から熱を発生させる加熱方法である[2]。木材加工においては，乾燥，接着，被覆，成形（変形）加工の一部で利用されている[3]。しかし，高荷重のプレスに高周波が設備された例はなく，また，これが圧縮木材の製造に応用された報告はない。本報では，実大サイズの圧縮木材の加熱処理による寸法安定化について，高周波加熱の効果を検討する。

2. 実験方法

2.1 供試材料

供試材料として，比重が0.34，平均年輪幅が3.6 mm，含水率が18%および全乾状態のスギ(*Cryptomeria japonica* D. Don)材を用いた。試験片寸法は，60(放射方向，R)×100(接線方向，T)×300および600(繊維方向，L)mmとした。試験片の木端面中央部に，光ファイバー温度センサー挿入用として，直径16 mm，深さ50 mmの孔を開けた(Fig. 1)。

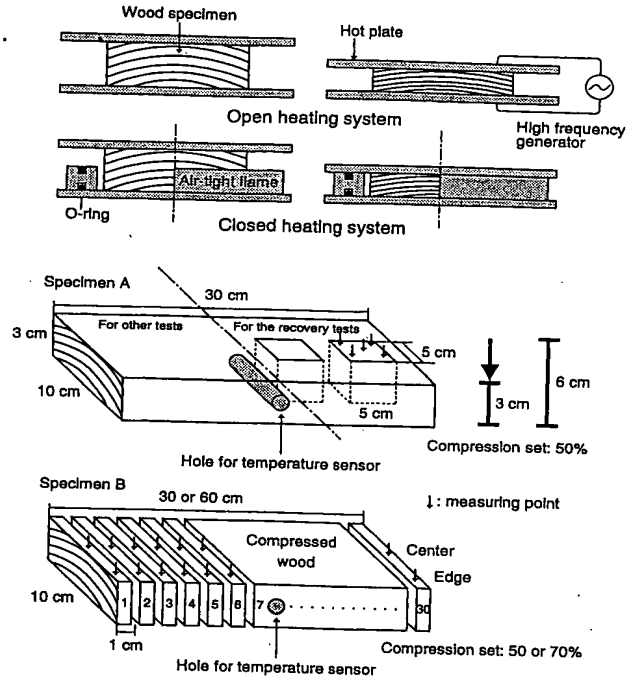

Fig. 1　Open (conventional hot pressing) and closed (hot pressing with air-tight frame) heating systems for the fixation of compressed wood and the sampling pattern of specimens for determining the set recovery.

2.2 圧縮試験片の調整

15 kWの高周波発振器（周波数：13.56 MHz）を備えた圧縮木材製造用プレス機を設計，製造した。本装置の最大負荷は1.96 MN，熱板寸法は750×550 mmである。これを用いて，密閉および開放加熱によって，仕上がり厚さが30 mmの大断面圧縮木材を製造した。圧縮前の試験片に7 kWの高周波を約30秒間連続印加し，100°C付近まで予備加熱した後，所定寸法に圧縮した。圧縮変形量は50，70%とし，ディスタンスバーおよび密閉フレームの厚さによって変形量を調整した。これらの治具には，高周波照射の影響を受けにくく，耐熱性に優れたベスサーモF(株式会社日光化成製)を用いた。圧縮成形が完了した時点で，再び高周波を印加し，材内部温度が200°Cになるまで加熱した。この時，熱板温度は200°Cに設定し，5.6 kWの高周波を30秒間インターバルで15秒間間欠発振を4回行った。すなわち，これに要する時間は約2分間であった。間欠発振の目的は，試験片内部と外気圧に許容以上の圧力差が生じることによる試験片の破壊を防ぐためであり，このスケジュールは予備実験の結果から最良と判断された。目標温度に達してから，2～8分間保持した後，流水

によって熱板を強制冷却した。材内部温度が70°C程度になってからプレスを解圧し，試験片を取り出したが，これに20～30分を要した。コントロールとして，高周波加熱を行わない場合についても実験した。各試験条件につき，2試験体を供試した。

2.3 試験片内部温度および密閉系内圧力の測定

加熱中の材内部温度を光ファイバー温度計（安立計器製　FX-8000）によって測定した。密閉加熱においては，密閉治具に装備したデジタル圧力計（株式会社バルコム製，VPMC-D-P-100.0K-1）によって，密閉系内の圧力を測定した。

2.4 水分・熱回復試験

Fig. 1 に示すように，A，B，2種類の回復試験を行った。Aでは，試験片中央部と端部2箇所から5 cm×5 cm を採取し，吸湿，吸水，煮沸，乾燥繰り返し試験を行った。吸湿試験は，相対湿度90%下に試験片を7日間放置し，吸水試験は，20°Cの水中に48時間浸漬して行った。煮沸試験は，吸水後の試験片を98°Cの熱水中で2時間煮沸して行った。乾燥試験は，試験片を1日以上風乾した後，40°Cで24時間，100°Cで6時間熱風乾燥して行った。各段階で厚さ方向（R）の寸法を測定し，回復度を計算した。回復度とは，与えた変形量に対する回復した変形量を百分率で表したものである。

Bでは，繊維方向に1 cm 間隔で木口試験片を切り出し，吸水，煮沸，乾燥試験を行った。吸水試験は，試験片を20°Cの水中で1時間減圧した後，6時間水中に放置して行った。煮沸試験は，吸水後の試験片を98°Cの熱水中で5分間煮沸して行った。乾燥は，Aと同様の条件で行った。吸水および煮沸後の試験片について，厚さ方向の全乾寸法を測定し，回復度を計算した。測定は，接線方向に対し，端部と中央部に分けて行った（Fig. 1 中の矢印）。

3. 結果および考察

3.1 材内部温度および密閉治具内部圧力

Fig. 2-A は，放射方向60 mm の試験片を50%圧縮変形する場合について，熱板加熱とこれに高周波加熱を併用した時の材内部温度の上昇を示す。200°Cの熱板だけで加熱する場合には，試験片内部温度が200°Cまで昇温するために，80分程度必要であるのに対し，高周波加熱を併用した場合では，わずか数分間で目的温度まで加熱することができる。また，密閉治具を用いた場合の治具内部圧力を Fig. 2-B に示す。密閉治具を用いて熱板のみで加熱した場合，密閉系内は，約18分後でも0.7 MPa にしか上昇していないのに対して，高周波加熱を併用した場合，約

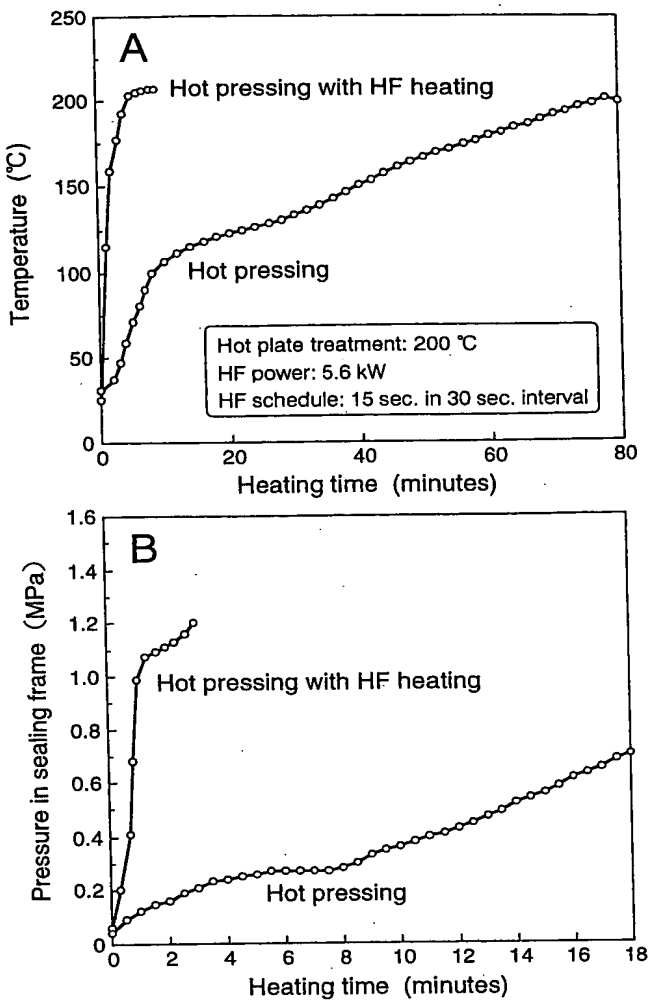

Fig. 2　Increases of temperature (A) and pressure (B) in the ari-tight frame during hot pressing with and without high frequency (HF) heating.

Note: Specimen size: refer to Fig. 1, 50% compression set.

1分間で系内は約1.0 MPa に達する。熱板加熱では，材料の熱伝導によって加熱が進行するため，木材のように熱伝導性の悪い材料では，大断面（熱板間距離が長い）を加熱するには長時間を要する。また，表層部より順次加熱されるため，圧力上昇に必要な水蒸気の発生量も緩やかとなる。それに対し，迅速かつ均一加熱が可能な高周波誘電加熱を併用すると，発生する水蒸気量が多く，密閉系内の圧力上昇も早くなる。

3.2 密閉加熱処理した圧縮木材の寸法安定性

Fig. 3-A に，密閉治具の有無および加熱方法の違いが，圧縮木材の吸湿，吸水，煮沸，乾燥繰り返しによる変形回復に及ぼす影響を示す。各処理条件と

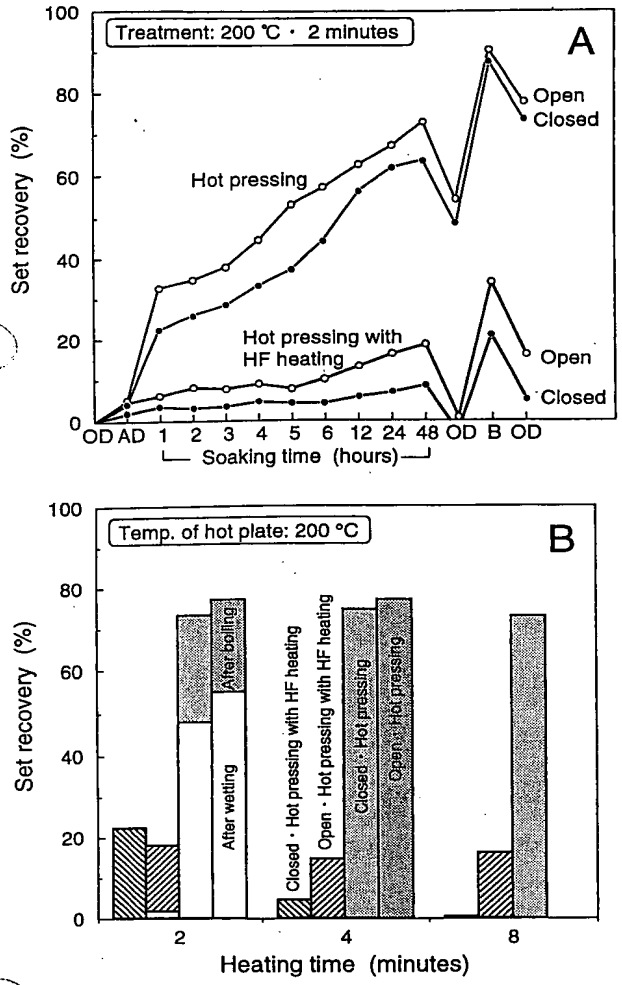

Fig. 3 The effects of closed and open heating systems and high frequency (HF) heating on the set recovery of compressed wood.

Note: Specimen: refer to Specimen A in Fig. 1, AD: conditioning at 90% RH (relative humidity) for one week, OD: oven drying at 100 °C for six hours, B: two hours boiling.

もに，相対湿度90%下に7日間放置した時の寸法変化は小さく，回復度の差はほとんど認められない。回復度は，吸水時間とともに徐々に増加するが，高周波を印加しなかった試験片の寸法回復が特に顕著である。熱板密閉加熱した試験片では，48時間吸水後全乾状態の回復度が50%程度であるのに対し，高周波を印加した試験片では，変形回復がほとんど認められず，寸法安定性に優れた圧縮木材が得られている。煮沸後全乾状態においても，高周波印加の有無によって，回復度は大きく異なり，熱板のみで加熱した試験片では，回復度が80%以上となる。この試験片を観察すると，圧縮方向に対し，中央部位での変形回復が顕著であり，試験片内部まで十分に加熱処理されていないことは明らかである。

Fig. 3-B は，上述の4条件について，煮沸後全乾状態での回復度と処理時間の関係を示す。密閉加熱であっても，高周波を印加しない試験片では，処理時間による差はほとんど認められず，回復度は70%以上である。前報[1]から判断すると，密閉加熱の場合，200°C，2分間加熱は，変形を永久固定するための十分な処理条件であるが，本実験との差は明らかに試験片の寸法効果である。大断面圧縮木材を熱板加熱のみによって加熱処理する場合，木材内部まで処理可能な温度に加熱するには，さらに長時間の加熱が必要となり，その際，表層部位は過度の処理によって強度性能が劣化し，材色も著しく変化するなどの不都合が生じる。強度性能や材色変化の詳細については，次報で報告する。一方，高周波密閉加熱した試験片の回復度は，2分間の処理では20%程度であるが，処理時間の増加とともに減少し，8分間の加熱処理で変形回復はほとんど認められなくなる。

以上，密閉加熱処理において，高周波加熱の効果が確認されたが，ここで，さらに注目すべき点は，密閉治具を用いなくても，高周波加熱を併用して製造した圧縮木材の寸法安定性が高いことである。本研究の目的は，簡便かつ実用的な大断面圧縮木材の製造技術の確立であり，大断面圧縮木材の用途として考えられる家具用材や住宅内装用造作材料では，煮沸に対するよりも吸湿，吸水に対する寸法安定性が高いことが重要であると考えられる。高周波加熱を併用して製造した圧縮木材では，吸湿，吸水による変形回復がほとんど認められず，さらに，煮沸のように過酷な回復条件での回復度が20%以下であり，これは内装用材料として高く評価される。そこで，以下に，高周波開放加熱処理について詳しく調べる。

3.3 回復抑制に及ぼす高周波加熱の効果

Fig. 4-A に，繊維方向が30 cm のスギ材を，200°C の熱板で，50%圧縮した試験片の吸水，煮沸による各部位の変形回復の一例を示す。図中，△，▽プロットは，熱板のみで加熱したコントロール試験片における結果を示し，▽はプレス圧締時間を同じにした場合，△は材内部温度が200°Cになるまで加熱した場合を示す。コントロール試験片では，両者とも，部位に関わらずドライングセット材とほぼ等しい変形回復が認められ，それぞれの回復度は，前者では約85%，後者では約70%である。これらに対し，高周波加熱を併用した試験片では，木口付近 3〜5 cm

の範囲は高い変形回復が認められるが，中央部付近は変形回復が抑制され，曲線はバスタブ状となる。この場合，中央部の回復度は，煮沸回復では約30%，吸水回復では5%以下である。

Fig. 4-B に，繊維方向が60 cm の試験片を用い，30 cm 試験片と同様の条件で製造した場合の結果を示す。変形回復が認められる部位の木口からの距離は30 cm の場合と同程度である。すなわち，高周波加熱を併用することによって，繊維方向長さによらず，木口付近の3～5 cm を除き，ほぼ寸法安定性の高い圧縮木材が得られることになる。前述の用途に圧縮木材を利用する場合，実際の製造では，2～4 m の木材が圧密化処理され，これが二次加工されて製なる。この時，木口から4～5 cm 程度は泥挽き囲であり，この程度の変形回復は実用上問題にらないと判断される。従って，高周波加熱によ縮木材の製造は，木材を開放状態で処理できるが簡便で現実性のある加工方法であると評価され

熱板温度を200°C，160°C，100°Cと変化させ，の実験を行ったところ，熱板温度の低下とともに復度は大きくなり，中央部の吸水回復による回復は，それぞれ，約5，15，35%である。熱板温度が10の場合，特に表面層付近の変形回復が顕著であ。これは，高周波の印加によって材内部温度は200°

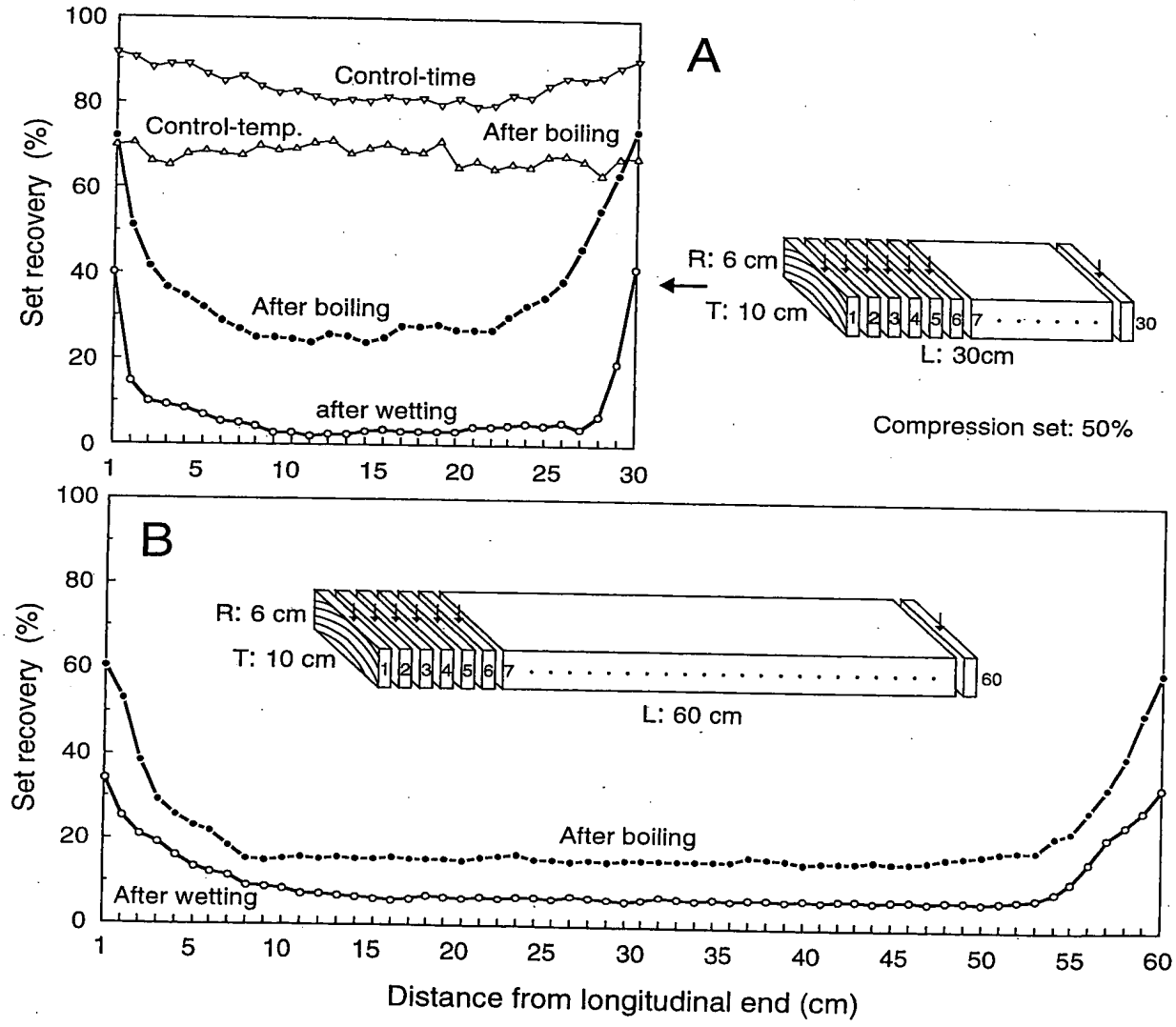

Fig. 4 The effects of hot pressing along with high frequency heating on the recovery of compression set after water soaking and boiling.

Note: Control specimens in the upper figure were heated by hot press for equal duration of heating (Control-time) and to the same temperature (Control-temp.) as when HF heating was applied.

で昇温しているが，熱板への放熱によって表面付近の温度が上昇しないことが原因と考えられる。従って，本加工法では，処理温度に加熱された熱板を併用することが不可欠である。冷却してサンプルを取り出す際の効率を考慮すると，熱板は，できるだけ薄く，熱容量が小さく，高効率の断熱材を介してプレス機定盤と連結するなどの工夫が必要となる。これらについては，次報で報告する。

3.4 高周波加熱による回復抑制の原理

熱板を用いて，開放状態で木材を加熱圧締すると，木材内部に発生した水蒸気は，内部圧力の上昇とともに木材中を移動し，両木口から外部へ噴出するため，温度上昇とともに木材は乾燥する。ところが，高周波エネルギーを急激に印加することにより，木材中に形状固定処理に必要な水分が残存している間に，木材内部を固定処理可能な温度（180～200°C）に昇温させることが可能となる。例えば，高周波加熱を併用する場合としない場合について，処理後の含水率は，前者が5～10%であるのに対し，後者はほぼ全乾状態にまで減少する。すなわち，高周波加熱を併用して圧縮木材を製造する時，木口付近の一部を除き，材内部は，高温，高圧，高含水率状態に保たれるため，密閉熱処理[1]と同様の原理で変形が短時間に固定されるものと考えられる。一方，木口付近は，外気にさらされるため，温度が上がりにくく，また，乾燥によって含水率が低下するため，回復抑制効果が発現しないと考えられる。

Fig. 5は，圧縮変形量が回復抑制効果に及ぼす影響を調べたものである。圧縮変形量を70%にすると回復度は小さくなり，特に，中央部の吸水による回復は全く認められなくなる。また，煮沸回復においても，中央部の回復度は10%以下になる。これは，単位体積あたりの木材実質量が増えることによって総含有水分量が増加すること，細胞内腔がさらに縮小することで木材内部の通気性が低下し，これによって水分を保持する効果が増加するためと考えられ，この結果は上述の原理に関する考察を支持する。

Fig. 6は，全乾状態の試験片を高周波開放加熱によって製造した圧縮木材の回復度を示す。全乾状態の木材では，煮沸回復による回復度が80%以上となり，これはドライングセット材の変形回復に等しく，何ら固定処理されていない。このことから，木材中の水分が回復抑制に寄与していることは明らかであり，この結果は上述の原理に関する考察を支持する。

この他，高周波加熱による変形の回復抑制効果について，化学反応において注目されている高周波照射の非熱効果[4]が考えられる。しかし，本実験の範囲では，非熱効果に関する有効なデータは得られなかった。

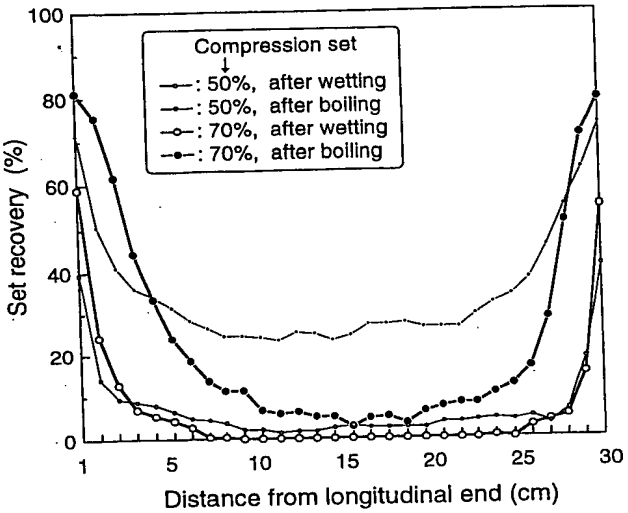

Fig. 5 The effects of the degree of compression set on the set recovery of high frequency heated compressed wood.

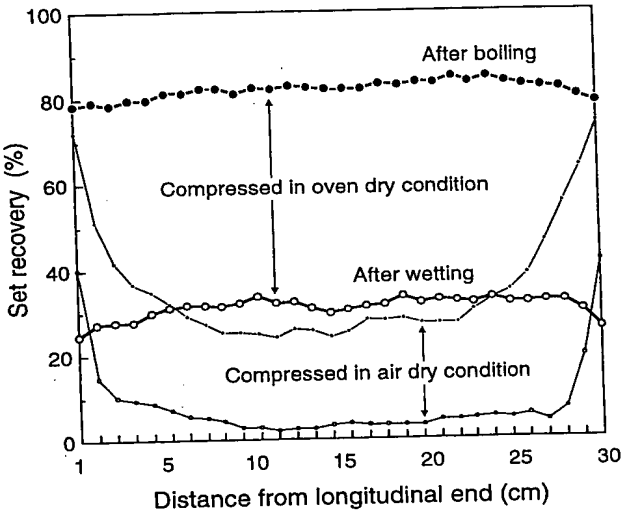

Fig. 6 The effects of initial moisture content of the specimens on the set recovery of high frequency heated compressed wood.

3.5 木端，木口拘束による回復抑制効果

回復試験片を詳しく観察すると，接線方向に対し，中央部と木端付近の変形回復に差が認められる。Fig. 7は，試験片の木口面から見た場合の端部と中央部の回復度を比較したものであるが，中央部に比べ木端付近の変形回復が大きい。この原因として，温度，含水率，圧密度の低下が考えられる。すなわち，木端付近は，熱板と接触していないため外気にさらされ温度が上昇しにくい。また，木端面からの

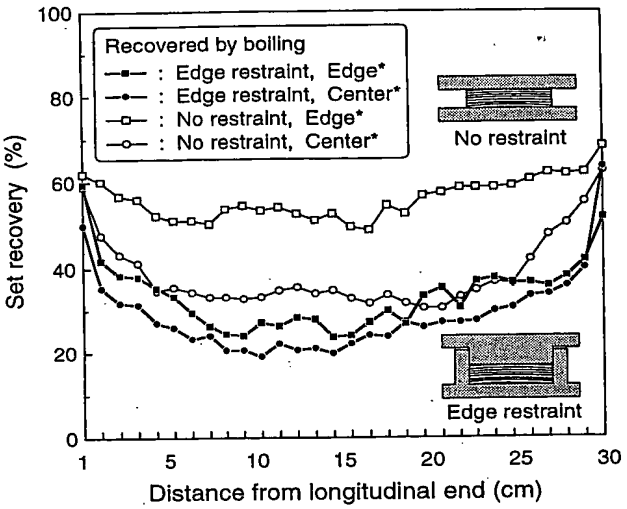

Fig. 7　The effects of edge restraint on the set recovery after boiling of high frequency heated compressed wood.

Note:　*: Refer to Specime B in Fig. 1 for the measuring points of test specimens in the compressed wood.

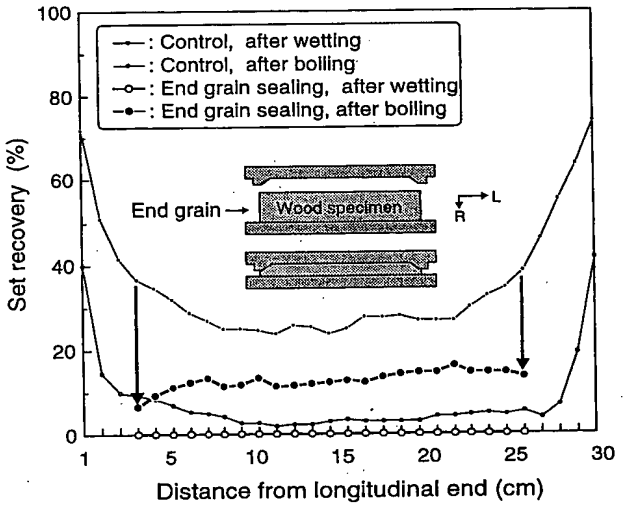

Fig. 8　The effects of end grain sealing on the set recovery of high frequency heated compressed wood.

水蒸気の噴出によって含水率が低下するため，Fig. 6で示した原理によって回復抑制効果が低下する。さらに，年輪傾角の違いによって圧縮方向に対する直角方向（接線方向）への材の伸張量に差が生じる。このため中央部に比べ木端付近の圧密度が小さくなり，Fig. 5で示した現象と同様に回復抑制効果が低下する。そこで，これらを防止するため，木端面を治具で拘束して圧縮変形することを試みた（Fig. 7中■，●）。これにより，木端付近の保温効果が上がり，蒸気の噴出が抑制でき，接線方向への木材の伸張が抑制されるため，木端付近の回復度を中央部とほぼ同程度まで減少させることができる。

Fig. 8は，高周波開放熱処理する木材の木口両端1.5 cm程度の圧縮量を約70%にすることで，木口付近の細胞内腔をさらに縮小し，材内部の通気性を低下させ，木口付近まで均一に回復抑制しようと試みたものである。これにより，木材全体の内部圧力を高くすることが可能となり，回復度は材全体にわたり低い値で安定する。特に，木口付近の回復抑制効果が顕著となり，さらに，吸水による回復は全く認められなくなる。

4. 結　　言

密閉加熱処理によって実大サイズの圧縮木材を寸法安定化させるには，高周波誘電加熱を併用することが有効である。さらに，密閉治具を用いない開放加熱であっても，高周波加熱によって木材を急激に加熱することにより，木材中の水分が蒸発する前に，材内部を処理可能な温度に上昇することができるため，木口付近を除き，密閉処理と同様の効果が得られる。また，高周波加熱は，短時間に，木材内部まで均一に加熱できるため，熱板に接する表面部位の強度性能の劣化や材色変化も少ない。

今後の圧縮木材の製造では，その用途に応じ，薄物（仕上がり厚さが5 mm以下）と厚物（仕上がり厚さが5 mm以上）に分けて研究開発する必要があると思われる。特に，厚物の製造においては，高周波誘電加熱の応用が不可欠となるであろう。

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2. Experiments

2.1 Specimens

Specimens were made of dried cedar tree (cryptomeria japonica D. Don) whose specific gravity were 0.34, average separation of growth rings was 3.6 mm and moisture content was 18 %. Sizes of the specimens were 60 mm (radial direction) × 100 mm (tangent direction) × 300 or 600 mm (longitudinal direction). Holes (diameter 16 mm and depth 50 mm) were bored in end faces of the specimens (see Fig. 1), and an optical fiber thermo sensor was inserted into the holes.

2.2 Preparing Compressed Specimens

A press machine for compressing the specimens were manufactured. The machine had a high frequency generator (frequency: 13.56 MHz). Maximum load of the machine was 1.96 MN, and a size of hot plates was 750 mm × 550 mm. The machine formed compressed specimens by close- and open-heating. Thickness of the compressed specimens were 30 mm. High frequency waves (7 kW) were applied to the specimens for about 30 seconds to preheat the specimens until reaching temperature of 100 ℃ before compression. Then, the preheated specimens were compressed to prescribed sizes. Compressibility of the specimens were 50 % and 70%. The compressibility were adjusted by a distance bar and thickness of a closing frame. These jigs were made of a material called "Besu Thermo" (trade name, manufactured by Kabushiki Kaisha Nikko Kasei, Japan), which has superior high frequency resistance and heat resistance. Upon completing the compression, high frequency waves (5.6 kW) were applied to the specimens again until reaching their inner temperature 200℃. In this step, temperature of the hot plates were 200℃, and the high frequency waves were applied for 30 seconds four times with intervals of 15 seconds. It took about two minutes to apply the high frequency waves. An purpose of the intermittent radiation of the high frequency waves was to prevent destruction of the specimens caused by unacceptable pressure differences between inner pressure of the specimens and outer pressure thereof. The schedule was selected according to pre-experiments. When the specimens reached the object temperature, they were held for 2-8 minutes, then the hot plates were compulsorily cooled by running water. When the inner temperature of the specimens reached about 70℃, the specimens were released from the compressing force. It took about 20-30 minutes. Further, experiments including no high frequency heating step were executed. Two specimens were used for each experimental condition.

2.3 Inner Temperature of Specimens & Inner Pressure of Closed System

The inner temperature of the specimens were measured while heating the specimens by the optical fiber thermo sensor (FX-8000, manufactured by Adachi Keiki, Japan). On the other hand, inner pressure of a closed system was measured by a digital pressure sensor (VPMV-D-P-100.0K-1, manufactured by Kabushiki Kaisha Barukomu, Japan) equipped with a closing jig.

2.4 Moisture and Heat Recovery Tests

As shown in Fig. 1, two kinds of recovery tests "A" and "B" were executed. In the recovery test "A", two samples (size: 5 cm × 5 cm) were taken from a center part and an end part of the specimen. Hydroscopic tests, water absorption tests, boiling tests and drying tests were repeatedly executed with the samples. In each of the hydroscopic tests, the samples were left for seven days with relative humidity of 90 % or less; in each of the water absorption tests, the samples were soaked in water (20℃) for 48 hours; in each of the boiling tests, the samples, which had absorbed water, were boiled in water (98℃) for two hours; and in each of the drying tests, the samples were air-dried for one day or more, then they were dried for 24 hours by hot wind (40℃) and for 100℃ by hot wind (100℃). In each of the tests, thickness R of the samples were measured so as to calculate degrees of recovery of the samples. The degree of recovery means percentage of an amount of recovery with respect to an amount of deformation.

In the recovery test "B", the specimen was cut at 1 cm intervals to form samples, and the water absorption tests, the boiling tests and the drying tests were executed with the samples. In each of the water absorption tests, the samples were soaked in water (20℃) for one hour with reducing pressure, then the samples were left in the water for six hours; and in each of the boiling tests, the samples, which had absorbed water, were boiled in water (98℃) for five minutes. The drying tests were executed as well as the drying tests of the recovery test "A". Thickness of the samples which had been completely dried were measured. The thickness at an end part and a center part of each sample, with respect to a tangent direction, were measured (see arrows in Fig. 1).